The Art of Thermal Mass Modeling for Energy Conservation in Buildings, Part 2

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ACI Spring 2012 Convention
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Linda Lam is a Project Engineer at Transsolar, Inc. She has a traditional mechanical engineering background with an energetic dedication to holistic design. Linda performs dynamic thermal simulations using Trnsys17 and assists with concept development for high-comfort and low-impact buildings design strategies. Linda has five years of experience with whole building energy modeling using software programs including Trnsys17, eQuest and IES VE. Her knowledge of standard and complex HVAC systems and familiarity with ASHRAE and IECC standards and codes facilitate a comparative understanding of energy benchmarks and requirements. In particular, she has been substantially involved on LEED new construction, core & shell and existing buildings projects.

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Thermal Mass Simulation Accuracy and Design Considerations

Linda Lam
1 March 2012

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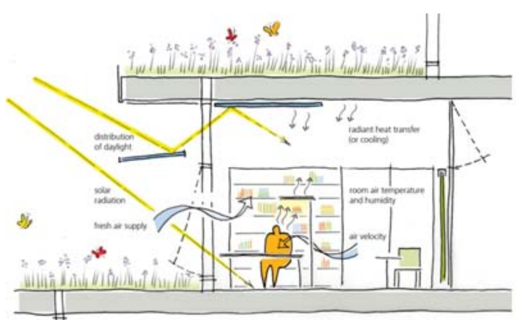

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1. Modeling Methods
   - heat balance model with the transfer function method (Trnsys 17.1 and EnergyPlus)
   - methods used in other existing thermal simulation engines (DOE2)

2. Thermal comfort evaluation
   - operative temperature
   - factors that maximize thermal mass potential

3. Examples of thermal mass applications,
   - active slab
   - night cooling
   - use in conjunction with a solar chimney

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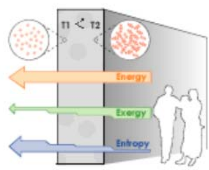
- Entropy: degradation of energy
- Exergy: the useable portion of energy

Exergy is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir.

- High temperature heating source typically waste exergy
- Low temperature heating increases the usable sources
  - Solar, ground source
- Similar for cooling
- Passive thermal design is partially about using low-exergy sources



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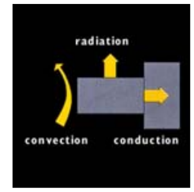
- Transfer of thermal energy toward a lower temperature heat sink takes place by:

  a) conduction
  b) convection
  c) radiation

- The heat flow rate through a body or through space is the amount of energy passing through in unit time, expressed in Joules/sec or Watts.

- The heat flux density is the heat flow rate per unit area, and is expressed in W/m^2.



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Transfer function method or response factors can be described as the method to tell the "thermal history" of the wall.

The walls are modeled according to the transfer function relationships of Mitalas and Arseneault defined from surface to surface

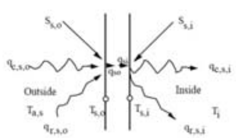

Figure 5.4.1-3: Surface Heat Fluxes and Temperatures

$$\dot q_{s,i} = \sum_{k=0}^{n_{bs}} b_s^k T_{s,o}^k - \sum_{k=0}^{n_{cs}} c_s^k T_{s,i}^k - \sum_{k=1}^{n_{ds}} d_s^k \dot q_{s,i}^k$$

$$\dot q_{s,o} = \sum_{k=0}^{n_{as}} a_s^k T_{s,o}^k - \sum_{k=0}^{n_{bs}} b_s^k T_{s,i}^k - \sum_{k=1}^{n_{ds}} d_s^k \dot q_{s,o}^k$$

"Thermal History"

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Material properties of the "real" wall are integrated into the transfer function equation system, to solve for coefficients and heat flux.

The simulation time-step, k, is high for heavy walls (k $\leq$ 20), and low for lightweight walls.

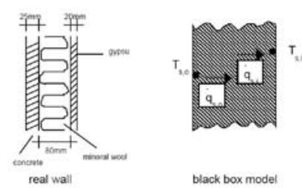

Figure 5.4.1-5: Real wall and black box model of the wall

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Transfer function method or response factors can be described as the method to tell the "thermal history" of the wall.

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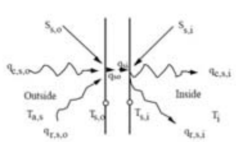

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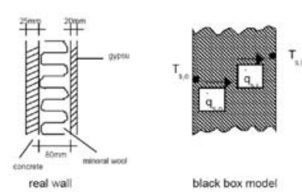

Figure 5.4.1-5: Real wall and black box model of the wall

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Weighting Factors are used in most common annual whole-building energy simulation tools because they require shorter simulation time.

Convective coefficients do not vary.

No history of temperatures from previous time step

Uses constant pre-calculated factors for entire annual simulation.

$$q_{inside}(t) = \sum_{i=0}^{\infty} Y_i \, T_{outside}(t-i\Delta) - \sum_{i=0}^{\infty} Z_i \, T_{inside}(t-i\Delta)$$

No history!

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Why bother?

- Knowing surface temperatures is key to radiant system controls
- Peak shift and reduction of loads is more accurately predicted and reduces the system size and first cost
- Thermal comfort is more accurately predicted

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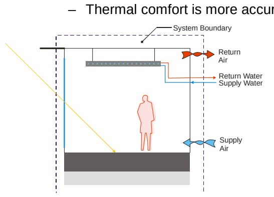
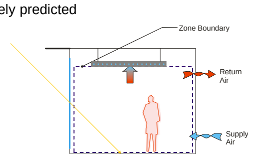


The system boundary provides capacities which inform the sizing of equipment.



The zone boundary reflects the energy balance occurring in the occupied space; the instantaneous heat flux into the surface

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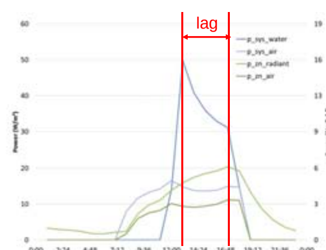

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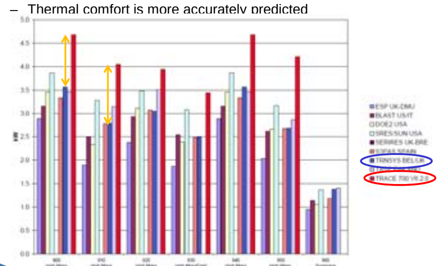

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Annual Cooling High Mass Building – BESTEST Evaluation for Analysis Software

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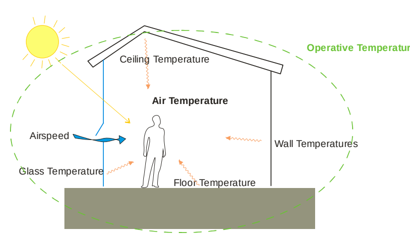

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Operative Temperature

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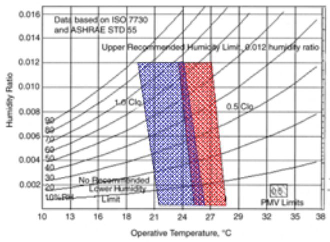

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ASHRAE 55 – Comfort Standard

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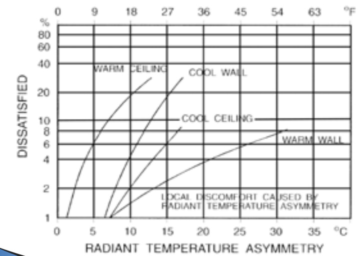

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ASHRAE 55 – Comfort Standard

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Maximizing thermal mass potential

- Sufficient shading and/or high-performance envelope
- Expanded basis of design
- Use in combination with semi-passive and active systems

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Sliding screens, curtains, etc.

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- Sufficient shading and/or high-performance envelope
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		(1) Design Conditions			(2) Typical Conditions*			(3) Extreme Permissible Conditions**		
Space Classification	Season	Air Temperature °F	Operative Temperature °F	Relative Humidity %	Air Temperature °F	Operative Temperature °F	Relative Humidity %	Air Temperature °F	Operative Temperature °F	Relative Humidity %
Class A: Exhibition Spaces	heating	68	68	45	70 ± 2°	70	50 ± 5%	65	65	10
Class A: Exhibition Spaces	cooling	72	72	55	70 ± 2°	72	50 ± 5%	78	78	40
Class B: Office Spaces	heating	68	68	20	68	68	10	60	60	10
Class B: Office Spaces	cooling	76	76	40	78	76	40	86	86	35
Class C: Lobby Spaces	heating	65	68	none	60	65	10	55	60	10
Class C: Lobby Spaces	cooling	80	78	60	80	78	60	86	86	35

* Typical conditions maintained for 80% of occupied hours, except for exhibition spaces always maintained
** Extreme conditions permitted during night setback or exhibition space vacancy (no setback for exhibition spaces)

- Definition of multiple thermal conditions
  - Design (system sizing)
  - Typical conditions (actual operation and comfort evaluation)
  - Extreme permissible (e.g. night setback)
- Definition of comfort metrics (operative temperature, PMV)
- Statistical evaluation of comfort
- Internal loads and occupancy for different occupancies

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Expanded Basis of Design

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Maximizing thermal mass potential

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- Use in combination with semi-passive and active systems

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Semi-Passive: Earth Duct

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Maximizing thermal mass potential

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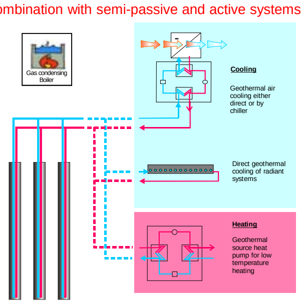
** for ground temperatures ~50°F)



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Semi-Passive: Direct Ground Coupling

Maximizing thermal mass potential

- Sufficient shading and/or high-performance envelope
- Expanded basis of design
- Use in combination with semi-passive and active systems

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Active slabs were first constructed during the 1930's but failed due to:

1. highly conductive building envelope (single pane glass, no insulation) required high heating capacities resulting in high surface temperatures.
2. prototypical open-loop steel piping systems had considerable contact with the ambient air and oxygen which lead to corrosion of the steel pipes.

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Active Slab: Success in Europe

- Thermal mass of the slab stabilizes the room temperature for comfort
- Noiseless
- Draft-free
- Inexpensive
- Provides both heating and cooling
- Air conditioning system size reduced; as low as supplying only the required fresh air
- No ductwork = higher ceilings
- Eliminates fan energy
- Reduced energy consumption
    - due to milder supply temperatures, heat pumps and chillers operate more efficiently
    - both heating and cooling energy can be generated from free sources such as ground water wells, wet cooling towers, etc.

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Active Slab: Unpopular in the US

- Indifference towards occupant comfort
- Energy costs are significantly lower
- Tendency to stick with tried-and-true air systems
- Concern that radiant systems will fail and cause lawsuits
- Duct industry supports all-air systems
- All-air systems initial costs are significantly lower

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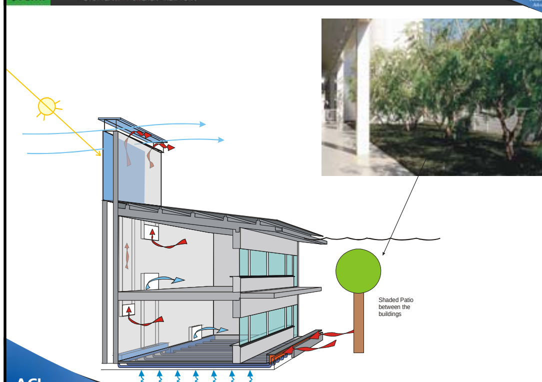

ACI WEB SESSIONS — Elementary School in Damascus - Summer day

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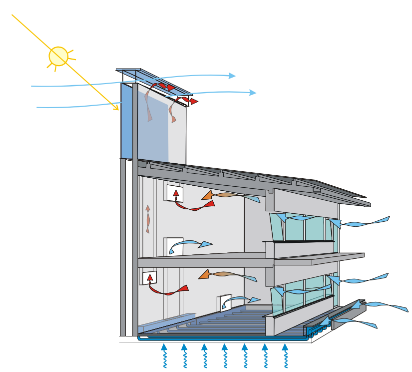

ACI WEB SESSIONS — Elementary School in Damascus - Summer night


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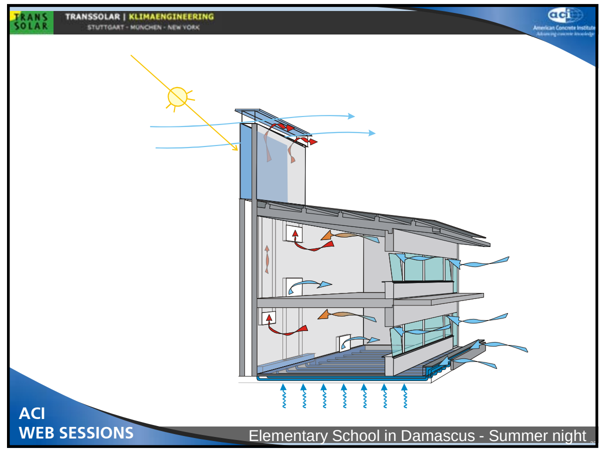
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Elementary School in Damascus - Summer night


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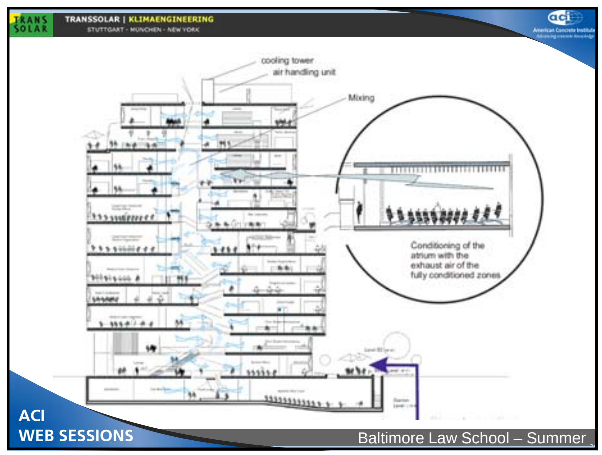
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cooling tower
air handling unit
Mixing
Conditioning of the atrium with the exhaust air of the fully conditioned zones
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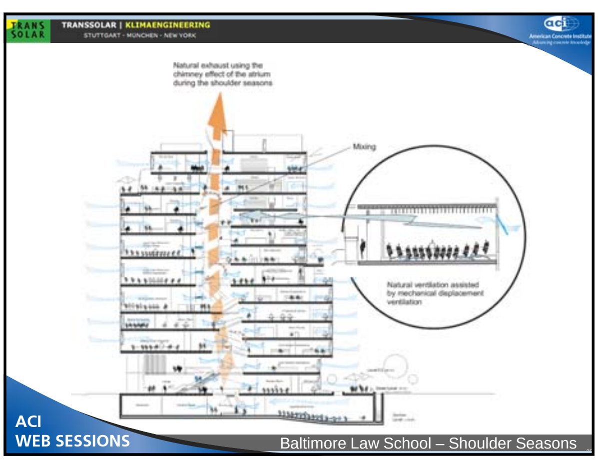
Baltimore Law School – Summer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Natural exhaust using the chimney effect of the atrium during the shoulder seasons
Mixing
Natural ventilation assisted by mechanical displacement ventilation
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Baltimore Law School – Shoulder Seasons


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Manitoba Hydro
Winnipeg climate ranges from
-35ºC to +34ºC (-31 ºF to 95 ºF)
2000 [comfortable] employees
100% fresh air, year-round
"Best Tall Building in North America"
(Council for Tall Buildings)
Energy performance monitoring
since 2010.
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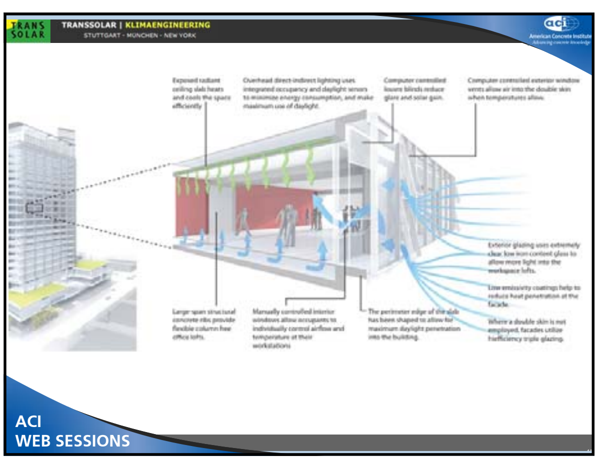
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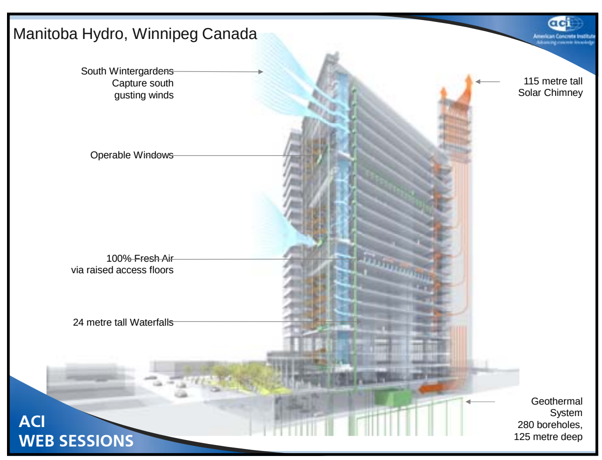
Manitoba Hydro, Winnipeg Canada
South Wintergardens
Capture south
gusting winds
115 metre tall
Solar Chimney
Operable Windows
100% Fresh Air
via raised access floors
24 metre tall Waterfalls
Geothermal
System
280 boreholes,
125 metre deep
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Thank you!

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lam@transsolar.com

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