Historic and modern homes that achieve 100% space conditioning with ambient energy

M. Keith Sharp

Renewable Energy Applications Laboratory
Department of Mechanical Engineering
University of Louisville

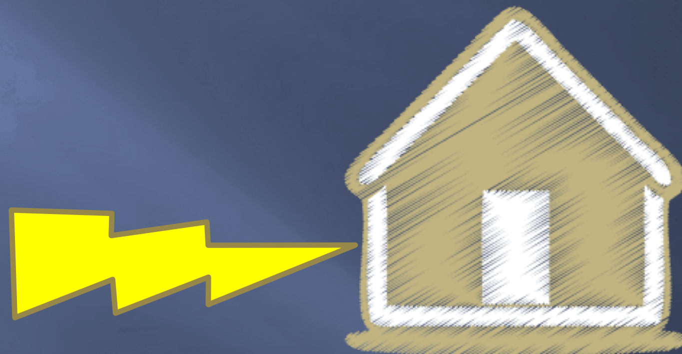
Richard Levine, ASES Passive Solar Pioneer, 1978:

The first steam powered vessels to cross the Atlantic looked like awkward sailing ships not steamships (just as the first automobiles looked like awkward carriages, not Model T's). They carried a full complement of sails because their reliability was well below 100%. It was not long before they achieved the reliability necessary to evolve their own form and their own structure, vastly different from the form of its progenitors.

Solar building is beginning to embark on this same sort of evolution – awkward, not able to do the job alone, working with adaptations of unsuitable existing forms. ***The turning point will be when we change our commitment from an add-on, booster mentality to a 100% solar sensibility.*** At that point evolution will be swift and irreversible. Solar devices, solar buildings and solar villages will rapidly develop appropriate forms and structures.

Conventional House:

T = *constant* with auxiliary energy



Ambient House:

$T_l \leq T \leq T_h$ with 100% Ambient Energy

Thermal Mass

Nighttime Ventilation

Sky Radiation

Dover MA Solar House. Maria Telkes 1948. 100% solar heated, 21 tons Glauber's salt storage. Image: Wide World Photo, the MIT News Office, and the MIT Museum.

Hay 1973 Atascadero, CA SkyTherm house. 8” roof pond. 100% solar heated and sky cooled. John Reynolds photo.

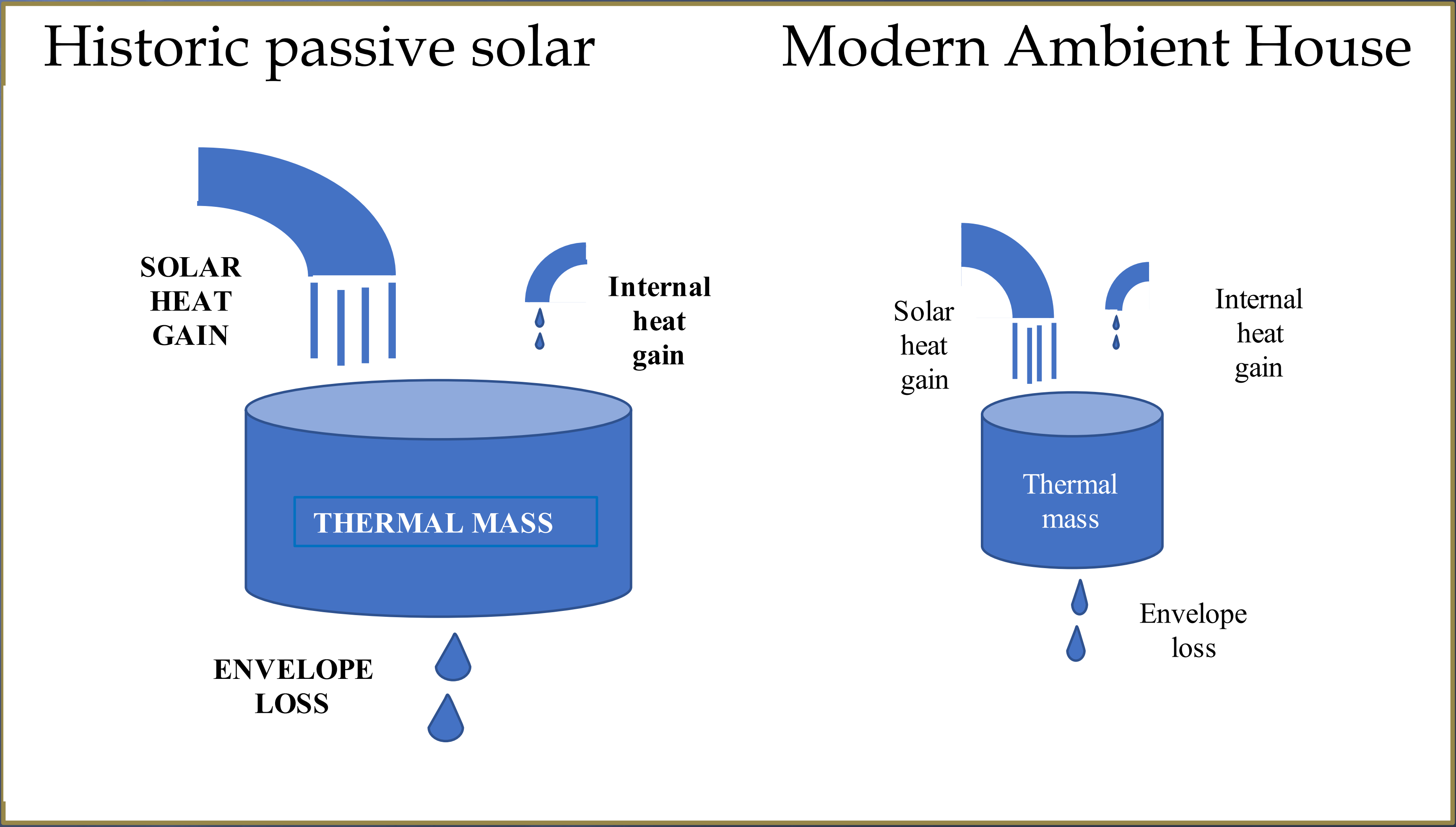
Shippee 1978 Longmont, CO SunEarth house. 97% solar heated and ventilation/earth cooled. Paul Shippee photo.

Warren/Saunders Boxborough MA house 1986. (Similar to Saunders Shrewsbury MA house 1981.) R30 walls, 18,000 gal water, 100 tons rock. 65-75 F year-round. WarrenDesign photo.

Riggins/Coleman 2011 Monument, CO house. ~100% ambient conditioned, 100% solar water heating, solar clothes drying, net zero electricity. Jim Riggins photo.

Sharp 2021 Pagosa Springs, CO house. ~100% ambient conditioned. Keith Sharp photo.

Evolution of passive solar



Building Energy Balance

Einstein: "Models should be as simple as possible, but not simpler"

- Conservation of Energy:
- with ventilation

$$mc_p \frac{dT}{dt} = F_s S A_c + G - UA(T - T_a) - F_v h A_v (T - T_a)$$

- with sky radiation

$$mc_p \frac{\partial T}{\partial t} = F_s S A_c + G - UA(T - T_a) - F_r A_r \sigma \varepsilon (T^4 - T_s^4)$$

- Solution of ODE:

$$\frac{T - T_0}{T_1 - T_0} = 1 - e^{\frac{4aT_1^3 + d}{mc_p} t}$$

Similitude parameters

- Solar Load Ratio

$$SLR = SA_c / UA\Delta T_o$$

- Internal heat Load Ratio

$$ILR = G / UA\Delta T_o$$

- Time constant

$$\tau = m\, c_p \Delta T_i / UA\Delta T_o$$

- Ventilation Load Ratio

$$VLR = (hA_v + UA)/UA$$

- Sky Load Ratio

$$SkLR = A_r \sigma \varepsilon (T^4 - T_s^4)/UA\Delta T_o$$

- Controls:
  - F_s - shading to eliminate S
  - F_v, F_r – ventilation/sky cooling

Building Energy Balance

Einstein: "Models should be as simple as possible, but not simpler"

- Conservation of Energy:
- with ventilation

$$mc_p \frac{dT}{dt} = F_s S A_c + G - UA(T - T_a) - F_v h A_v (T - T_a)$$

- with sky radiation

$$mc_p \frac{\partial T}{\partial t} = F_s S A_c + G - UA(T - T_a) - F_r A_r \sigma \varepsilon (T^4 - T_s^4)$$

- Solution of ODE:

$$\frac{T - T_0}{T_1 - T_0} = 1 - e^{\frac{4aT_1^3 + d}{mc_p} t}$$

Similitude parameters

- Solar Load Ratio

$$SLR = SA_c / UA\Delta T_o$$

- Internal heat Load Ratio

$$ILR = G / UA\Delta T_o$$

- Time constant

$$\tau = m\, c_p \Delta T_i / UA\Delta T_o$$

- Ventilation Load Ratio

$$VLR = (hA_v + UA)/UA$$

- Sky Load Ratio

$$SkLR = A_r \sigma \varepsilon (T^4 - T_s^4) / UA\Delta T_o$$

- Controls:
  - F_s - shading to eliminate S
  - F_v, F_r – ventilation/sky cooling

Building parameter comparison

	Envelope losses, Btu/hr ft^2 F	Thermal mass, Btu/ft^2 F	Solar window area, % of floor area	Internal heat gain, W/ft^2	January solar load ratio	January internal heat load ratio	Time constant, days
Telkes	0.35	6159	63.5	0.515	0.8	0.131	95.6
Hay	0.39	160	100	0.518	0.735	0.064	3.76
Shippee	0.176	41.9	19.2	0.338	1.067	0.246	1.19
Saunders	0.201	251	44.1	0.318	0.758	0.141	6.79
Riggins	0.0524	6.39	8.4	0.26	1.072	0.454	0.575
Sharp	0.0458	15.89	6.2	0.191	0.808	0.345	1.75

Very similar 0.7 – 1.1

Larger for modern

Except for Telkes, similar and climate appropriate

Conclusions

100% heating and cooling with ambient energy is possible

Historic passive solar

- Large envelope loss
- Large solar gain

Modern Ambient House

- Small envelope loss
- "Just right" solar gain

Solar Load Ratio ~ 1

- Large thermal mass

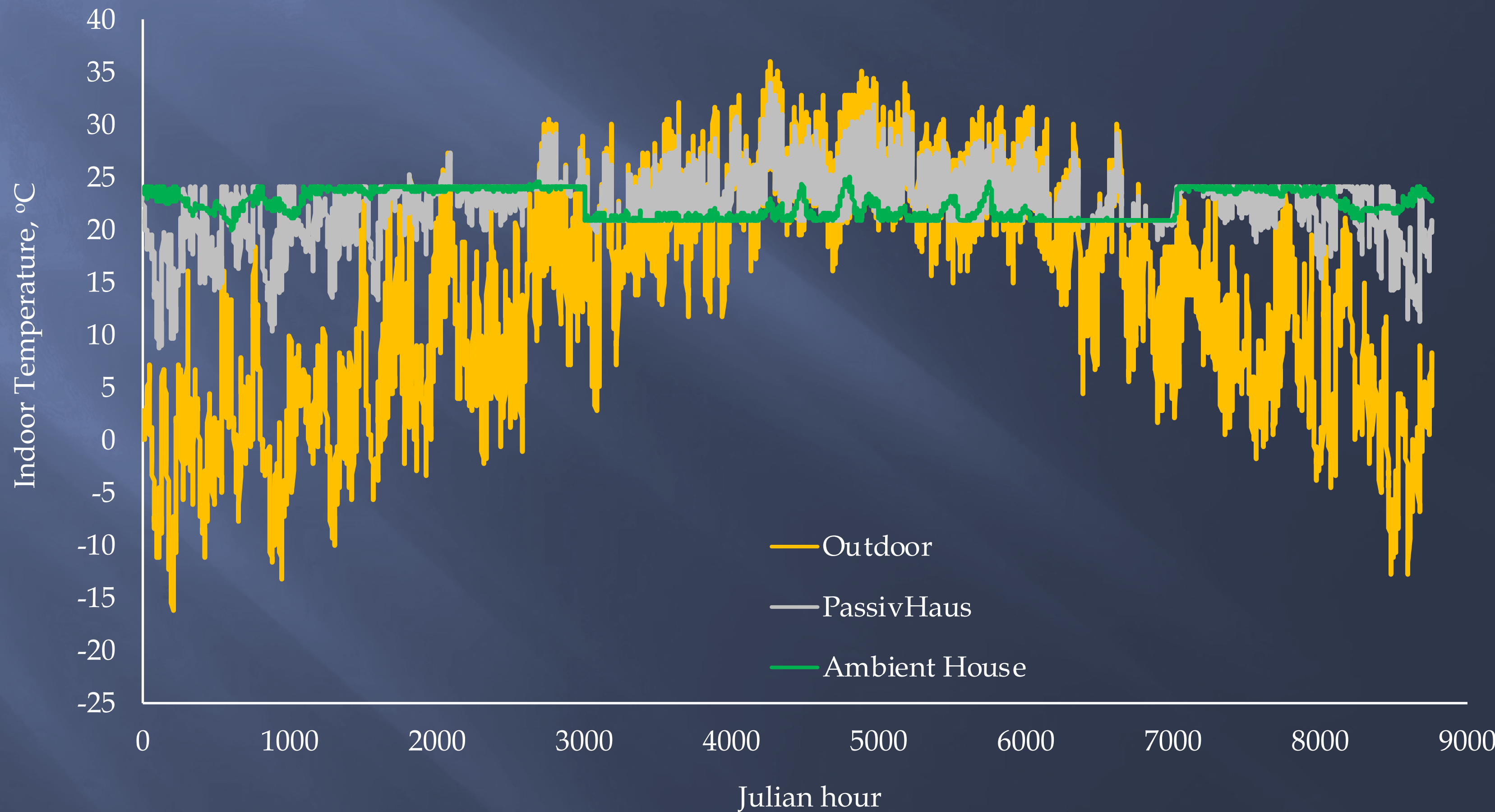
- Smaller thermal mass

Thermal time constant > # cloudy days

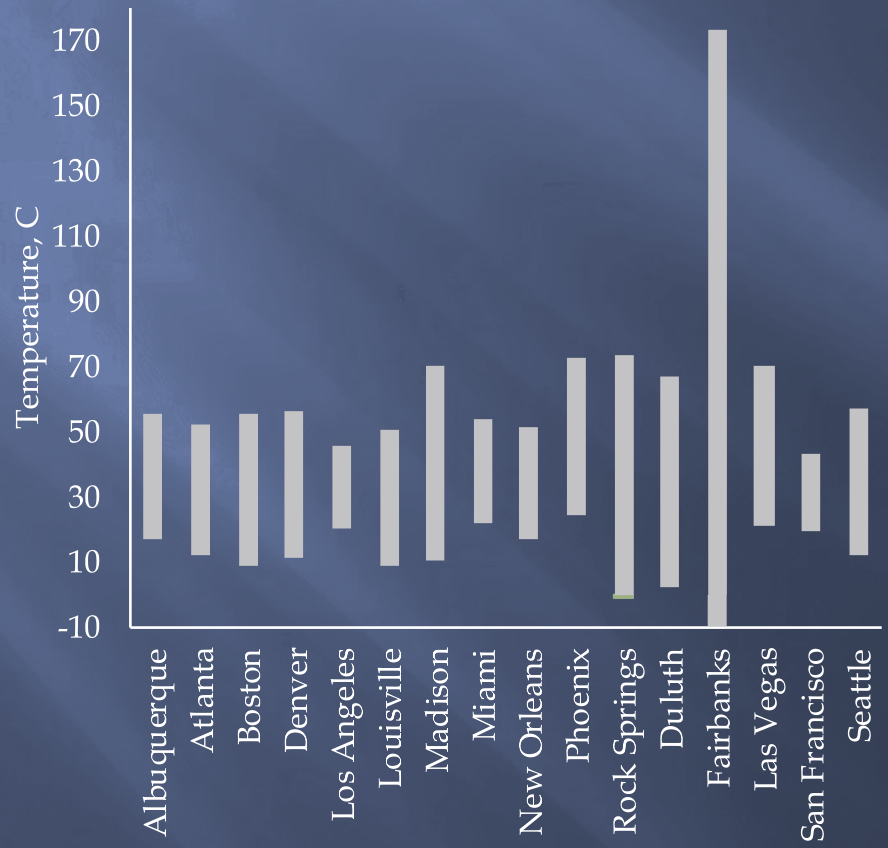

keith.sharp@louisville.edu

Backup slides

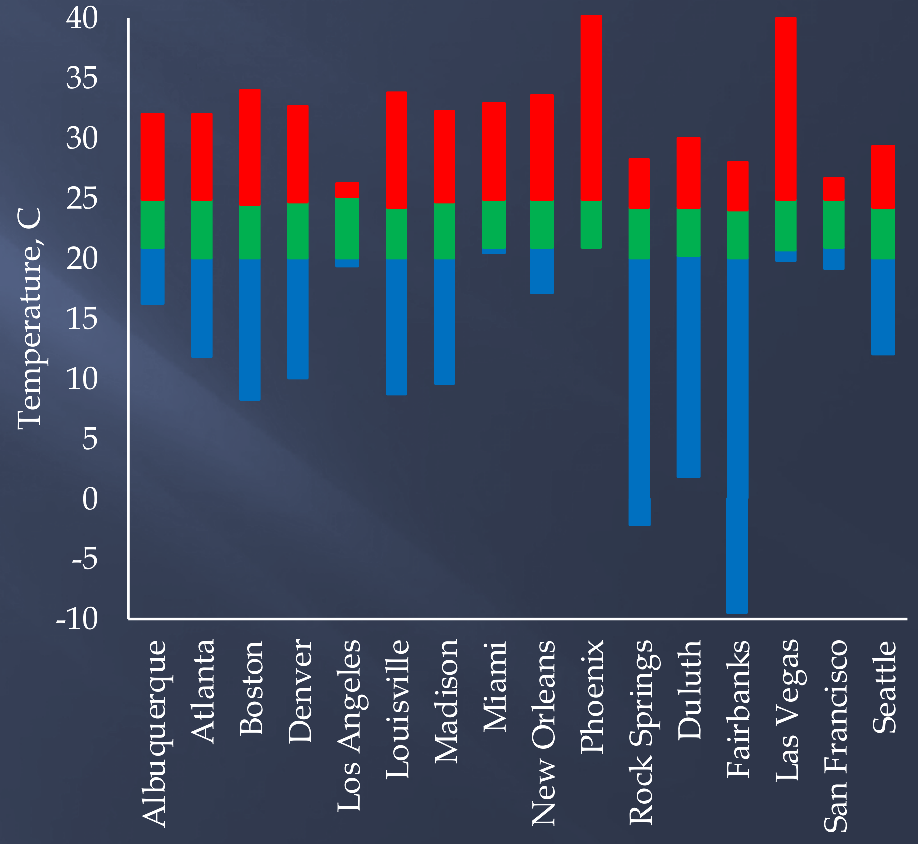
Example House
Louisville, KY



Ambient House vs Passive House Performance with TMY weather data



Passive House – no controls



Passive House – with controls

Green – Ambient House (20 – 25 ^oC)

Ambient House characteristics

Envelope losses U

- 0.428 (Los Angeles) – 0.228 (Phoenix) W/m^2 K (matched to Passive House)

Internal heat gains G

- 4.05 W/m^2 a typical value

Solar aperture A_c/A

- 0.05 (many locations) - 0.3 (Fairbanks)

Ventilation $(hA_v + UA)/UA$

- 10 (many locations) - 10000 (Miami)

Sky radiation A_r/A

- 0.5

Thermal mass mc_p/A

- 53 (Los Angeles) – 14000 (Phoenix) kJ/m^2 K conventional 125 – 452 kJ/m^2 K

Time constant $mc_p\Delta T_i/UA\Delta T_o$

- 0.52 (Los Angeles) – 136 (Phoenix) days