EXAMINING FEASIBILITY of THERMAL MASS for PASSIVE HEATING and COOLING in the PACIFIC NORTHWEST

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What is Thermal Mass?

Scientifically, thermal mass is equivalent to thermal capacitance or **heat capacity**, the ability of a body to store thermal energy.

In building design, thermal mass is a property of the mass of a building which enables it to store heat, providing "inertia" against temperature fluctuations. For example, when outside temperatures are fluctuating throughout the day, a large thermal mass within the insulated portion of a house can serve to "flatten out" the daily temperature fluctuations, since the thermal mass will absorb thermal energy when the surroundings are higher in temperature than the mass, and give thermal energy back when the surroundings are cooler, without reaching thermal equilibrium. This is distinct from a material's **insulative value**, which reduces a building's thermal conductivity, allowing it to be heated or cooled relatively separate from the outside, or even just retain the occupants' thermal energy longer.

Thermal mass, correctly used, moderates internal temperatures by averaging out diurnal (day–night) extremes. This increases comfort and reduces energy costs.

Poor use of thermal mass can exacerbate the worst extremes of the climate and can be a huge energy and comfort liability. It can radiate heat to occupants all night as they attempt to sleep during a summer heatwave or absorb all the heat produced on a winter night.

How Thermal Mass Works:

-Thermal mass acts as a thermal battery. During summer months it absorbs heat during the day and releases it by night to cooling breezes or clear night skies, keeping the house comfortable. During the winter the same thermal mass can store the heat from the sun or heaters to release it at night, helping the home stay warm.

-Thermal mass is not a substitute for insulation. Thermal mass stores and re-releases heat; **insulation** stops heat flowing into or out of the building. A high thermal mass material is not generally a good thermal insulator (see Rammed earth).

-Thermal mass is particularly beneficial where there is a big difference between day and night outdoor temperatures, i.e. large **diurnal swings**.

-Correct use of thermal mass can delay heat flow through the building envelope by as much as 10–12 hours, producing a warmer house at night in winter and a cooler house during the day in summer (Wilson 1998). (see 'Thermal lag' below)

-A high mass building needs to gain or lose a large amount of energy to change its internal temperature, whereas a lightweight building requires only a small energy gain or loss to change the air temperature. This is an important factor to consider when choosing construction systems and assessing climate change adaptation.

Flow chart

Does the local daily temperature swing at least 12.6° F?

- **Y → Hot climate?**
  - Why is this important? Thermal mass is most appropriate in climates with a large diurnal temperature range. As a rule of thumb, diurnal ranges of less than 6°C are insufficient; 7°–10°C can be useful depending on climate; where they exceed 10°C, high thermal mass construction is desirable. Exceptions to the rule occur in more extreme climates.
  - **Y → Humid?**
    - Why is this important? High humidity holds latent heat in the air and thus is its own thermal mass, which in turn can make additional thermal mass a liability.
    - Y → We're sorry, thermal mass can be a liability, use ventilation and lightweight construction.
    - N → Congratulations, you can use thermal mass to passively heat and cool your building!
  - **N → Southern exposure?**
    - Why is this important? In the northern hemisphere, the southern side of the building is the side that will potentially receive the most sunlight throughout the day.
    - Y → Congratulations, you can use thermal mass to passively heat your building!
    - N → No luck on solar, but thermal mass can be used around an internal heat source!
- **N → Large internal thermal loads?**
  - Why is this important? Heat generated by people, lighting, and equipment is called internal thermal load, also known as core load or internal gain. Lighting and most equipment loads are sensible heat, while the metabolic heat generated by peoples bodies are a combination of sensible and latent heat. Some buildings or spaces are dominated by less common internal sources of sensible and latent internal loads such as large kitchens, swimming pools and locker rooms and health clubs or industrial processes.
  - **Y → Congratulations, you can use thermal mass to help maintain tempera-tures within your building!**
    - Why is this important? Thermal mass can reduce peak cooling loads and indoor air temperature swings inside buildings.
  - **N → Hot climate?**
    - Why is this important? In hot climates internal thermal mass can increase heating costs and the time required to heat the space.
    - Y → We're sorry, go spend your money on insulation or other strategies, we're done here.
    - N → No luck being passive, but high mass construction works well regardless!

Key: Cooling strategy — Heating strategy — Neutral strategy

Passive Wind / Convection Cooling

Allow cool night breezes and/or convection currents to pass over the thermal mass, drawing out all the stored energy. During the day protect the thermal mass from excess summer sun with shading and insulation if required.

Passive Solar Heating

Allow thermal mass to absorb heat during the day from direct sunlight or from radiant heaters. It re-radiates this warmth back into the home throughout the night.

Internal Thermal Mass

Allow thermal mass to absorb heat from an internal source, and reradiate that heat back into the building when the heat source is no longer or present.

Rule-of-thumb glass to mass ratios for different climates (Passive Solar Heating):

Cold and alpine climates: Double glazed areas of 20–25% of floor area (drapes should be used for night time insulation on the glazing)

Cool temperate climates: Double glazed windows, again with drapes 15–20% of floor area

Temperate climates: glass area 12–15% of floor area (17% if double glazed)

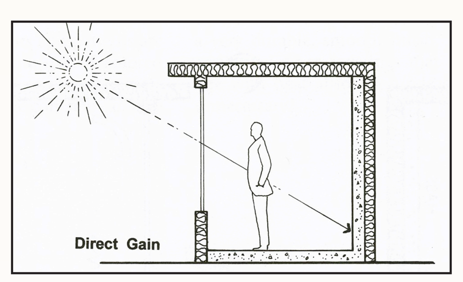
Cooling dominated climates: The ratio of solar exposed south-facing glass (in the Northern Hemisphere) should be at least 6% but up to 10% can be useful depending on design.

Cooling only climates: Solar exposed glass should be avoided; low mass construction with high level ventilation is usually best. Earth coupled slabs can add useful 'heat wicking' properties to thermal mass where mass covered ground temperatures at 1.5m depth remain below 19°C in summer.

Source: http://www.yourhome.gov.au/passive-design/thermal-mass

3 Types of Passive Solar Heating Systems Using Thermal Mass:

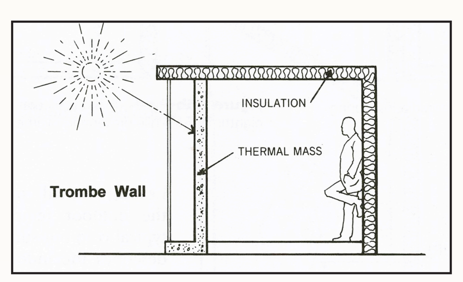
Lechner, Norbert's Heating, Cooling, Lighting: Sustainable design methods for architects, 3rd ed., 2009



Direct Gain: In this system, the building and its contents collect solar heat directly through south facing windows. All building contents (furniture, drywall, books, etc.) collect heat, however the contents usually cannot collect and store enough heat, and thus exposed thermally massive walls and floor slabs are needed.

-Pros: Inexpensive, most efficient, can effectively use clerestories, heating and daylighting strategies are combined, flexible design solutions.

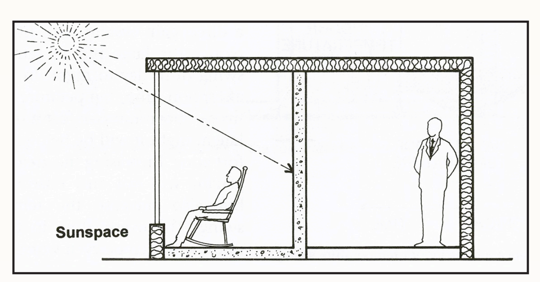
-Cons: Glare and fading colors due to excessive daylight. Carpets cannot be placed on massive floors intended for thermal storage. Similarly, few paintings can be hung on thermally massive walls. Overheating can occur. Large and slow temperature changes must be tolerated.



Trombe Wall: A thermally massive wall, typically masonry, placed just inside of south-facing glazing. Greenhouse effect is used to trap solar heat gain and allow it to slowly absorb into the thermally massive wall.

-Pros: Provides high level of thermal comfort. Works well in combination with direct gain to limit lighting levels. Costs are mid-range. Good for large heating loads.

-Cons: More expensive than direct gain. Less glazing available for daylighting and views. Not effective in cold or cloudy climates.



Sunspaces: Formerly called "attached green-houses" (which was misleading because growing plants is only an optional function), sunspaces are adjunct rooms designed to collect heat and radiate it to the main building volume as well as serve as a secondary living space.Temperatures can swing widely in these spaces.

-Pros: Aesthetically pleasing design solution. Extra living space. Can function additionally as a greenhouse.

-Cons: Simultaneously the least efficient and most expensive system.

Wall Assemblies - Traditional Thermal Mass

Concrete

HEAT CAPACITY*: 30 btu/ft³ °F.
PROS: High compressive strength, extremely shapable
CONS: Heavy, expensive installation

https://urbantimes.co/2014/04/6-easy-steps-to-beautiful-sustainable-architecture/

Brick Masonry

HEAT CAPACITY: 25 btu/ft³ °F.
PROS: Stable, aesthetically pleasing
CONS: Labor intensive, heavy, seismic considerations

http://inspectapedia.com/Solar/Passive_Solar_Design_Elements.htm

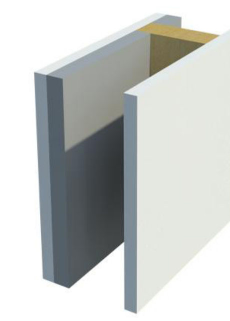
Water

HEAT CAPACITY: 62 btu/ft³ °F.
PROS: Cheap, abundant, extremely high heat capacity
CONS: Requires containment, leak potential

http://www.designrecon.com/sunrooms/passivesolar.html

Wall Assemblies - New Technologies

Phase Change Materials



HEAT CAPACITY: Varies significantly
TYPES OF MATERIALS: hydrated salts, paraffin waxes, fatty acids and eutectics of organic and non-organic compounds.
SELECTION: PCMs should first be selected based on their melting temperature depending on application. Materials that melt below 15 C are used for storing coolness in air conditioning applications, while materials that melt above 90 C are used for absorption refrigeration. All other materials that melt between these two temperatures can be applied in solar heating and for heat load leveling applications.

-Materials to be used for phase change thermal energy storage must have a large latent heat and high thermal conductivity.
-They should have a melting temperature lying in the practical range of operation, melt congruently with minimum subcooling and be chemically stable, low in cost, nontoxic and non-corrosive.

PRECEDENT 1:
Lauck, Jeffrey Stephen, "Evaluation of Phase Change Materials for Cooling in a Super-Insulated Passive House" (2013). Portland State University: Dissertations & Theses. P. 1444.
-This study examined an actual passive house in Portland, Oregon, which had been experiencing overheating due to minimal air changes. Air and surface temperatures were monitored, and it was discovered that in the case of this particular type of construction, phase change materials did indeed have a positive effect on thermal comfort.
PRECEDENT 2:
Campbell, Kevin Ryan, "Phase Change Materials as a Thermal Storage Device for Passive Houses" (2011). Portland State University: Dissertations & Theses. Paper 201.
-This paper shows efficiency tests of BioPCMs in a passive house in cities in four different climate zones, including Portland, Oregon. The study reveals that PCMs are actually quite successful in cooling second floor residential rooms during summer months in Portland.

Lightweight Aggregate Concrete

HEAT CAPACITY: 17 btu/ft³ °F
COMPOSITION: 25% cement, 25% Kaolin clay, and 50% softwood aggregate (wood chips 1/8-1/3 inch diameter) appears to be the most advantageous combination for maximizing strength to weight ratios.

-Wood/clay/cement composites exhibit double porosity; which greatly improve the thermal conductivity, but reduce the overall thermal capacity.
-Wood/clay/cement composites have a lower overall compressive strength than traditional concrete, but the nature of the wood-matrix aggregate bond is predictable and mixtures can be formulated to a specifically desired strength.
-The use of wood chip, a common lumber production by-product from a renewable resource, requires less energy to produce and transport than mined and washed stone aggregate.

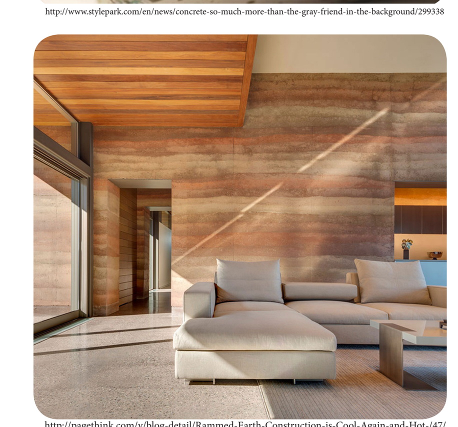
PRECEDENT:
Barquin, F. and Bouguerra, A. and Dheilly, R. M. and Ledhem, A. and Queneudec, M. Effect of Microstructure on the Mechanical and Thermal Properties of Lightweight Concrete Prepared from Clay, Cement, and Wood Aggregates. Laboratoire Ba^timent: Universite' de Picardie Jules Verne, Le Bailly, France: December 1997.
-This study found that wood aggregates greatly improve the thermal conductivity of the composite.
-The results of the compressive strength tests indicate that the wood aggregate-clay-cement composites satisfy the requirements for both primary and secondary construction applications, depending on the mass content of the wood aggregates.
THERMAL TESTING RESULT:
The average of two tests in the Green Building Research Lab at Portland State University on Dec. 3rd 2014 resulted in a K value of 1.39 Btu/hr°/ft²/°F

Rammed Earth

HEAT CAPACITY: 25 btu/ft³ °F (adobe)
COMPOSITION: This varies depending on the project location. The primary material used in rammed earth construction is, as the name implies, the earth itself. There are five basic types of soil (gravel, sand, silt, clay, and organic), and the dirt in a given location is generally some combination of all or most of these types. Historically, the longest lasting rammed earth walls were made of soil that was 70% sand and 30% clay.

-Rammed earth is probably the single lowest environmental impact building system that is readily and commercially available today for solid masonry buildings.
-This wall type is low cost, readily available, high thermal mass (comparable to concrete and brick), however rammed earth has low compressive strength (up to 620 PSI), difficulty in designing forms, soil selection is critical.

Read more: http://www.madehow.com/Volume-1/Rammed-Earth-Construction.html#ixzz3O5uRsw



PRECEDENT 1:
Out-of-the-Box Passive Solar
by SIREWALL (Stabilized Insulated Rammed Earth)
Salt Spring Island, British Columbia
Out-of-the-Box Passive Solar. (n.d.). Retrieved December 10, 2014, from http://www.sirewall.com/portfolio/residential-projects/out-of-the-box-passive-solar/
-This residential project demonstrates the use of thermal mass as a successful strategy when combined with other passive and energy-saving technologies, specifically in the Pacific Northwest.
PRECEDENT 2:
Evaluating rammed earth walls: a case study
by P. Taylor and M.B. Luther, Deakin University, Australia.
-This study looked at a rammed earth office building in NSW Australia, with climactic conditions very similar to the pacific northwest (cool wet winters, and hot dry summers). Rammed earth was used as thermal mass in conjunction with stack ventilation.

Abstract

Traditional developer-driven multifamily housing is often cheaply constructed, inefficient, and architecturally far-from-compelling. Generally, market forces in this type of project dictate the decision process down to the smallest details. THA is interested in elevating the level of design in this type of work by integrating passive solar strategies utilizing thermal mass. Research was needed to determine if thermal mass strategies could be used in the Pacific Northwest, and if the alternative wall constructions could provide a compelling argument for implementation in regards to the long-term cost-effectiveness of the passive technologies. Due to dynamic cost variables, the research focused on climatic responses, material choice, and basic passive thermal mass design.

Experimentation & Research

Research direction was initially prompted in response to a current project in Portland, Oregon. Focus shifted, however, to looking at regional use of thermal mass due to the project and the class' differing timelines, as well as the difficulty of using thermal mass in a cold, cloudy climate.
Research revealed that there are several key factors to consider when implementing a thermal mass strategy for passive solar heating and cooling in the Pacific Northwest. Most importantly a diurnal temperature swing of at least 12.6°F must occur in order for thermal mass to effectively transfer its latent heat load for passive heating or cooling. Due to the complex nature of climatic conditions, a flow chart was developed as an educational tool.

Traditional thermal mass materials have been thoroughly studied, with a great deal of information available in most climate conditions. Several new thermal storage material technologies have become available on the market with limited or no (proprietary) research available. Small testable wall assemblies were created and tested for their thermal properties in the Green Buildings Research Lab at Portland State University.

Essentially, thermal mass could be helpful in the Pacific Northwest in some very specific circumstances, such as within a passive house, however cannot be added without a developer's desire to be on board with the use of numerous passive strategies together.

Project Timeline:

PROJECT SCOPE
- Meetings with stakeholders
- Establishment of project scope
- Feasibility analysis of goals
- Developed Research Proposal

RESEARCH
- Group research into thermal mass and related passive strategies
- Thermal mass material strategy
- Individual research in material choice

Phase Change Material
Rammed Earth
Lightweight Concrete

- Update to project vision
- Case studies for the Pacific Northwest
- Material acquisitions

TESTING & ANALYSIS
- Familiarization of available equipment
- Analysis of testable results
- Creation of wall assemblies

- Meetings with stakeholders
- Redirection of project scope
- Group analysis planning
- Testing of wall assemblies

OBSERVATIONS & CONCLUSIONS
- Conceptualization of new project vision
- Organization of research data
- Deeper investigation of case studies
- Creation of thermal mass flow diagram

- Conclusion: thermal mass can be used as a passive strategy in the Pacific Northwest with specific climate related parameters