Adobe and Latent Heat; A Critical Connection

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Abstract

A series of ongoing experiments provide evidence supporting the opinion that "Adobe is warmer in the winter and cooler in the summer". Two modules were constructed, one each of adobe and cinderblock. Both have 8 inch walls and same internal dimension with roofs and floor of the same material. With an outdoor ambient temperature of 98° F, interior temperatures were 90° for adobe and 103° for the cinderblock. Why the13° difference? The adobe module *lost* 8° by way of latent heat of vaporization in accord with known properties of soil; the cinderblock *gained* 5° due to simple heat conduction.

Adobe is soil and remains soil after incorporation into a building and thus adobe is subject to the thermal dynamics of soil. A reverse effect occurs when adobe takes on moisture when humidity is high and temperature are low. During cold weather data loggers for temperature and moisture were placed in each of the modules over a total of ten days. During each diurnal cycle the lowest and highest temperatures were restricted to the cinderblock.

Simple experiments are provided to illustrate the thermal properties of adobe (*i.e.*, soil). Phase change from liquid water to vapor, or the reverse, will result in a very high latent heat that serves to lower or raise the temperature of adobe.

Clay, the binder for adobe, is hygroscopic and moisture content varies with changes in moisture availability. Such variations preclude adobe being assigned a specific heat capacity as is the case with conventional building material.

One cannot restrict evaluation of adobe to the parameters of sensible heat, as does the building industry, and ignore known principles of soil science especially as concerns the role of latent heat. Experimentation by the author provides strong evidence that as a construction material adobe blocks keep a building warmer in the winter and cooler in the summer than cinder block. The explanation for this phenomenon lies in the role of latent heat, not sensible heat – a critical distinction.

Introduction

Use of cinder blocks for construction of small buildings, especially housing, has almost completely replaced adobe along the Texas-Mexican border. In the border city of Ciudad Acuña, across the river from Del Rio, Texas, perhaps as much as 95% of new home construction is cinder block. However, the trend along the border is a reflection of a trend global in dimension in lands once wedded to earthen material for small buildings – dominantly the non-industrial world. But where adobe had once ruled the belief of the populace persists: "Adobe is cooler in the summer and warmer in the winter" than other type building material. If such is true is there supporting data? The answer appears to be yes and it is associated with *la-tent heat.* While there are inherent insulating properties of adobe given an *R* –value of .25 per inch, latent heat appears to have been overlooked as an additional factor to consider.

Adobe differs profoundly from all other type building material in that *adobe comes from soil and remains soil after incorporation into a building.* Latent heat, especially of vaporization and condensation, is of elementary concern to soil science. Attempts to evaluate adobe exclusively in terms of sensible heat, as with the use of the *R*-value or thermal mass, has resulted in confusion in evaluating adobe in terms of thermal properties.

Adobe and its suitability for exceptionally hot climates, as exists along the Texas-Mexican border, is of special interest to this study. Concern for cold weather conditions has tended to dominate concerns for building material in general and adobe in particular due to reasons of geography. Adobe vs. cinder block construction is studied with a series of simple experiments including the use of two modules, one of cinderblock and one of adobe. All studies were conducted in Del Rio, Texas in 2004.

Two Modules

Experiment 1: Two modules, one each of adobe and cinderblocks (CMUs) with 8" walls were constructed with floors and roofs of identical material and dimensions. The former was stuccoed with cement; the later with lime.. Outside dimensions of both modules are approximately 5′2″ x 4′ x 2′2″ with interior volumes about 22 ft^3 each.

Figure 1. ***Experimental modules.*** Cinderblock left; adobe right. With ambient temperature of 98° F, temperatures inside the modules were 103° F for the cinderblock and 90° F for the adobe; a difference of 13°. The cinderblock was 5° F above ambient and the adobe 8° F below it. Recording of data was made 27August 2004 at 4:30 p.m. Modules are located at the *Casa de la Cultura* in Del Rio, Texas.

Why so significant a difference as 13° F? Reference to R-values or thermal mass cannot fully explain the difference. An adobe wall, 8" thick, has an R-value of 2 (.25/inch for adobe) and R-value of1.08 for the cinderblock. With a lower R-value, the cinder block would be expected to exhibit a higher inside temperature but not the extreme of 13° F. It should be noted that the cinderblock was *above* ambient temperature; the adobe was *below* ambient.

In ***Experiment 2a*** data loggers were emplaced in each of the two previously described modules during acute cold weather from the 25th to the 30th of January, 2004. Data was recorded for temperature, relative humidity and dew point but only temperature data is illustrated in Figure 2a and 2b.

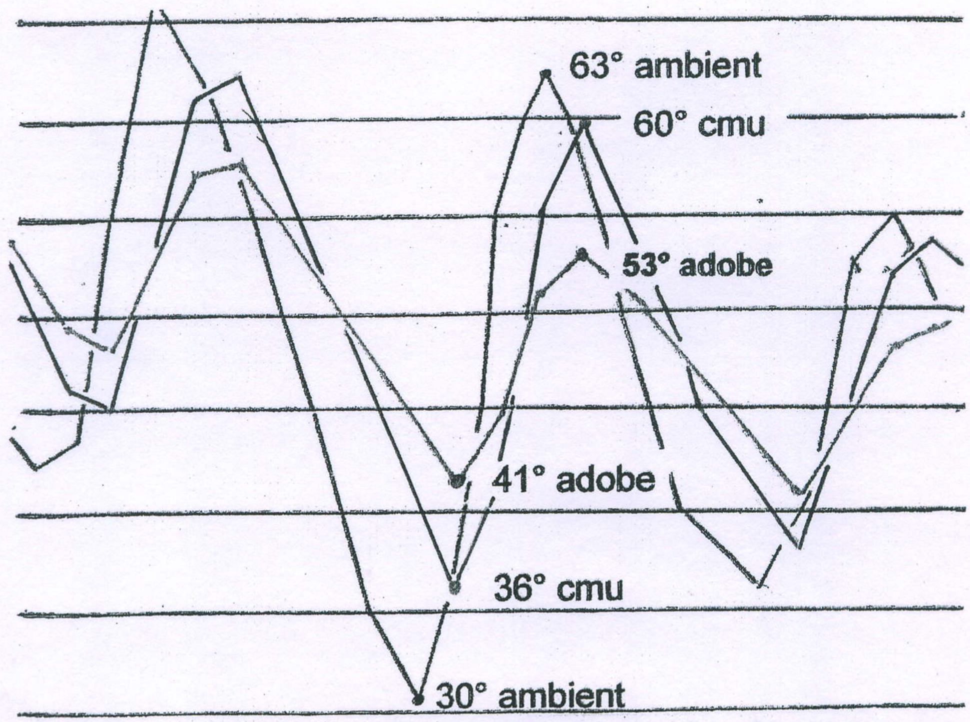


Figure 2a. *Enlargement of the data for the most extremes of temperature for the 27th of January, 2004.* For that day, the range of temperature was 12°F for the adobe and 24 °F for the cinder block.

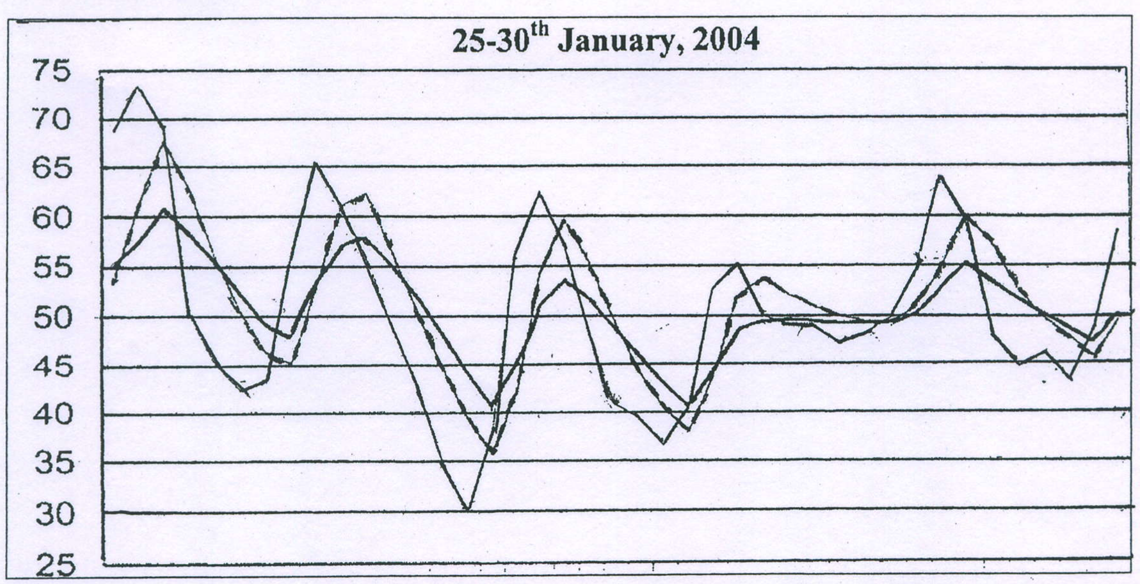


Figure 2b. *Temperature data loggings for 25 to 30th of January 2004 during a cold period.* Heavy black line - adobe; dashed line - cinderblock; light line - ambient temperature. Note that with respect to temperature extremes, for any given time, that that the cinderblock records temperatures higher and lower than the adobe. Fluctuation of temper-

ature is noticeable less for the adobe than for the cinder block. Detail is provided on the next figure

Experiments on Latent Heat of Vaporization/Condensation

Latent heat, especially of vaporization, is first demonstrated with simple experiments prior to more discussion. The initial experiment is concerned with a) the nature of clay, b) permeability and c) evaporative cooling or latent heat of vaporization.

Experiment 3 serves to demonstrate the heat of vaporization. Four small flower pots are utilized: 3 plastic and one slightly larger of clay. One plastic pot is painted black, one painted white and the third is left its red clay-color. The clay pot is left with its natural clay color. Each of the pots, with their bottom holes sealed, was filled with 500 ml of water and covered with an appropriately colored plastic lid and placed in full sun. Ambient temperature at the time was 94°F in the shade. After being left in the full sun for three hours (2:00-5:00 pm), data is recorded in **Figure 3.**

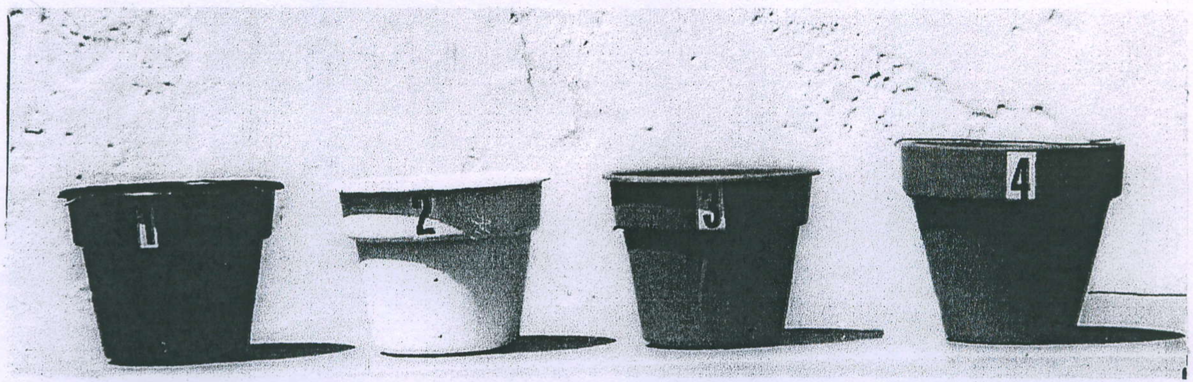


Figure 3. *Plastic and clay flower pots and vaporization of water.*

Ambient temperature -- 94 °F

#1 black	**113°F**	**+19°**	**No measurable loss of water**
#2 white	**102°F**	**+8°**	**No measurable loss of water.**
#3 natural clay color	**105°F**	**+11°**	**No measurable loss of water.**
#4 clay pot	**86°F**	**-8°**	**56% loss of water**

The most dramatic difference is in the temperature of the clay pot; actually 8° below ambient; all the plastic pots were well above ambient. *The clay pot was 19° cooler than its color counter part in the plastic pot.* But note the large amount of water the clay pot lost. An explanation is that the clay pot was water proof in that liquid water would not flow out of it but it remained permeable to water vapor that readily diffused through the sides of the pot. Such movement of water molecules involved a phase change from liquid to water vapor resulting in the latent heat of vaporization. For each gram of water going from liquid to a vapor state about 580 cal/gram of heat (540 cal/gram for vaporization with the boiling of water) are removed from the clay pot. As the clay pot lost 280 ml of water (one ml of water is equal to one gram) by diffusion there was a total of some 160,000 cal/gram of heat removed from the water! As the heat lost is incorporated into the vaporized water molecules themselves, it is not subject to measurement by a

160,000 cal/gram of heat removed from the water! As the heat lost is incorporated into the vaporized water molecules themselves, it is not subject to measurement by a thermometer nor can it be felt – it is thus 'hidden' heat or latent heat of vaporization as opposed to 'sensible heat' – heat that can be felt and measured.

The plastic pots, being impermeable to water vapor, evaporative cooling was not possible. The difference in temperature of the plastic pots is associated with differing capacity of colors to absorb solar radiation. Black is mostly absorbing radiant energy and white mostly reflects it. The rather dark natural clay color is in between. The contrasting colors of black and white translate into 11° difference between the plastic pots.

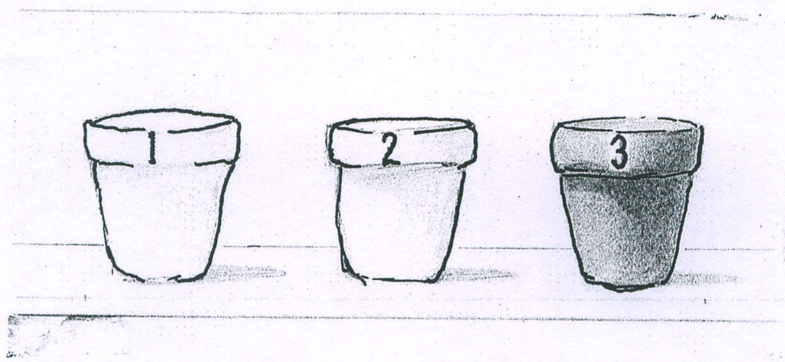
Experiment 4 demonstrates the important role of clay and aggregates (sand and silt) in adobe with a simple experiment. Besides serving as the binder in adobe, clay also exhibits important thermal dynamics. There are two factors to consider. 1) Clay particles carry a negative charge and thus water, a polar compound, is readily attached to clay particles; 2) simple diffusion of water vapor from high to low concentration occurs in connection with clay as there is a daily change in the amount of vapor in the atmosphere over a 24-hours. The aggregates provide for capillary action and movement of water molecules in and out of the adobe.

Figure 4. *Moisture absorption of clay in response to changes in relative humidity.* Outdoor exposure of a cube of compressed earth block to ambient condition of temperature and humidity August 20 – 24, 2003, Del Rio, Texas 2003. Weights were recorded in early morning and late afternoon.

High RH- a.m.	*Low RH – p.m.*	*Weight loss of moisture*	*Total loss of heat*
261.0 g	**257.9 g**	**3.1 g**	**1,674 cal**
261.0 g	**257.4 g**	**3.6 g**	**1,944 cal**
260.2 g	**258.4 g**	**1.8 g**	**972 cal**
261.2 g	**258.7 g**	**2.5 g**	**1,350 cal**

Percent of weigh gain may be small but the latent heat of vaporization is extremely high. The amount of heat involved is directly tied to the specific heat of water that is much higher than any building material.

Experiment5. Three clay pots: one painted with white enamel, one painted with white lime wash and one is left a natural clay color. The experiment is designed for a two-fold purpose. One is to answerer the question of what evaporative cooling would be with clay pots filled with water with one pot painted with white enamel; one with a lime wash, and one unpainted clay pot and all exposed to the full sun. Second, is to determine the difference in white color – one with an enamel rendering and interfering with evaporative cooling, the other with a lime wash that is highly permeable to water vapor.



Ambient temperature of 94°F.

1 Limewash - 78 °F	**2 Enamel paint - 94 °F**	**3 Unpainted - 88 °F**
- 16 ° below ambient	***no change***	***- 6 ° below ambient***

The lime washed clay pot is now *16° below ambient temperature!* Why? Because the high reflectance of the white lime wash significantly limits the amount of radiant energy absorbed to convert into thermal energy as sensible heat but it remains vapor permeable *and thus permits evaporative cooling.* The white enamel pot succeeds in greatly reducing the conversion of radiant to thermal energy but because it is impermeable to water vapor it *prevents* evaporative cooling.

Experiment 6 is to determine the temperatures difference between clay pots painted white with one a natural clay color when no evaporative cooling can occur (Figure 6).

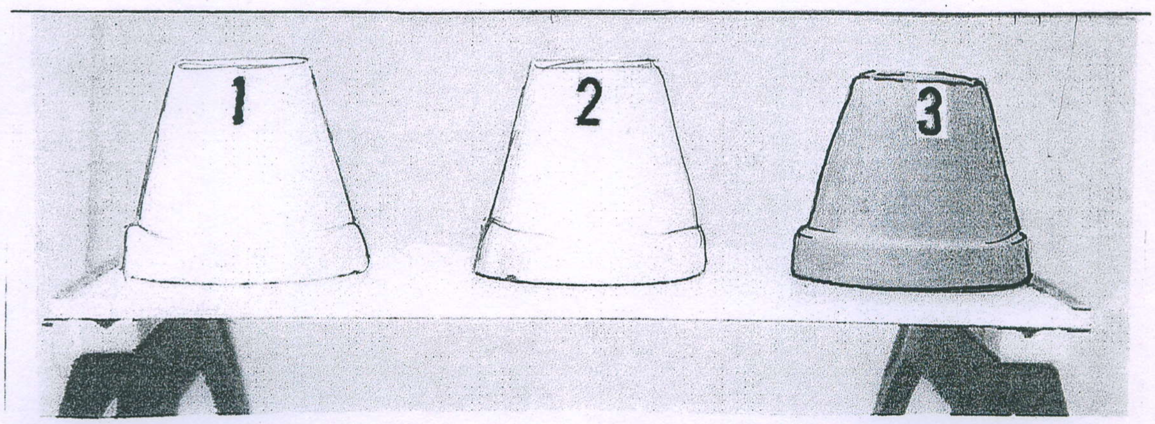


Figure 6. ***Large clay pots turned upside down exposed to ambient condition in full sun*****; # 1 enamel white; # 2 white lime wash; # 3, natural clay color. Inside temperatures recorded after three hours exposure and subsequent gain in temperature is recorded.**

Ambient temperature -- 94°F

#1 104°F	**#2 98°F**	**#3 104 ° F**
+ 10 °	**+4°**	**+10 °**

It will be noted that the lime wash is more effective in reflecting solar radiation. Lime wash is a mixture of slaked lime (calcium hydroxide) and water. When applied as a near water-thin paint it sets slowly by absorbing CO_2 from the air to produce crystals of calcite ($CaCO_3$, calcium carbonate). Unlike most paints that are organic polymers lime wash is a mineral of *dual reflective index* and thus more effective in reflecting solar radiation. The lime wash is 6° lower than the enamel.

Latent Heat and Building Materials:

Use of latent heat, especially heat of fusion, has been of interest to the building industry since at least the 1940s. Attempts have been made using various substances, but not water, and incorporating them into building material to produce what is known as phase-change materials. The intent is to provide thermal storage by latent heat in the building fabric. The advantage is that they would be able to store energy in latent form, as well as by sensible means, leading to greater heat storage capacity per unit volume than of conventional building materials. The concern has focused almost entirely on providing warmer indoor temperature in the winter. However, the material being used for that purpose, waxes in some instances, all have lower latent heat of fusion than water.

The nature of adobe vs. cinderblock

Clay is the binding material of adobe with silt and sand serving as the aggregate often with the addition of organic matter by way of straw or horse manure. In construction of an adobe block, *clay remains chemically unaltered.* The water simply serves to compact and rearrange the adobe particles. The clay of the adobe block retains its capacity to attract water and water can move in and out *via* capillary action in response to available moisture. With Portland cement a highly complex and altered aggregate of very fine powder undergoes a chemically transformation into concrete when mixed with water and an aggregate. While some capacity for capillary action remains it is much reduced compared with adobe or other earthen building material. Importantly, the clay content of Portland cement has been chemically altered and is no longer hygroscopic. This distinction between earthen material and products incorporating Portland cement or stone and brick building material, is critical to appreciating thermal qualities of both.

A Scaled-up Model.

How does one scale up from the small modules previously discussed for a realistic view of the thermal properties of a home dwelling? Some insight is provided by a study published in *Earthbuilder, 10th Anniversary Issue* 42, 1984, p. 56, Adobe News, Inc. The house, described as an "old style adobe", was located in Los Lunas, Rio Grande Valley, New Mexico at an elevation of 4,750 feet. The building had 17-inch thick walls and an earthen roof 8 to 12 inches thick. Temperature was recorded in two intervals – before and after an expansion. Initial floor plan, under 1,000 ft^2 is illustrated below (**Figure 7**).

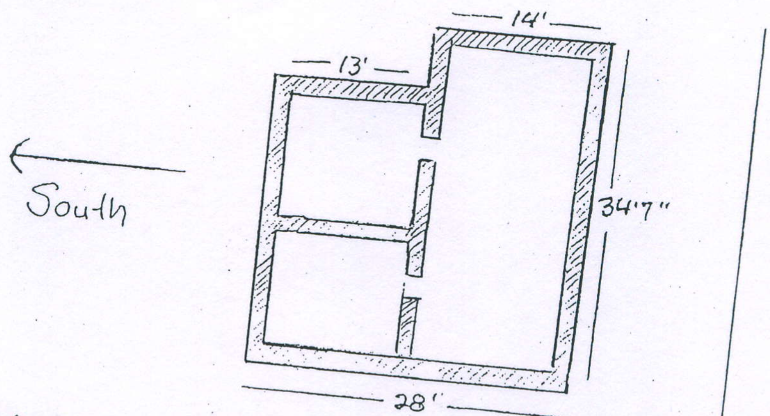


Figure 7. *Original floor plan as of June 14, 1976.* No insulation employed. No cooling mechanisms or overhangs. The building was kept closed during data gathering. One window on the north side. Minimal shading: large tree on the NW side of house gave partial shade on the corner late in the day.

Temperature data for the adobe house on June 14, 1976:

Time	*Inside Temp.*	*Outside Temp.*
12:30 pm	79.0	99.0
1:30 pm	79.5	101.5
2:30 pm	80.0	102.0
3:30 pm	80.0	99.5
4:30 pm	79.0	88.0
6:30 pm	79.5	89.0

Inside temperature of the adobe did not exceeded 80° F when outside temperatures average in the mid- to upper 90s. Note that when outside temperatures were 102° F, inside temperature was 80° F – a 22° difference! The authors comment that there was an inside temperature variation of only 5° from May 27 to July 11 and further note that there was no roof insulation; no evaporative cooing or cooling of any kind. Significantly, the authors comment that "It was noted that the inside *high temperature* occurred during the *a.m. hours*, and roughly 12 hours after the outside high of the preceding day. Likewise, the inside *low* appeared in mid to *late afternoon*, roughly 12 hour during the morning outside low temperature." (Emphasis added). That inside temperatures of an adobe house would be cooler when outdoor ambient temperature is highest and warmer inside when outdoor temperatures are coolest is clearly counterintuitive! However, the adobe is responding, not to sensible heat of the environment, but rather to a differential of moisture content on either side of an adobe enclosure.

Latent heat of condensation would be expected to occur in the morning hours when relative humidity is highest and outside temperature is coolest. The absorption of moisture by the clay in the adobe would result in *raising the temperature of the adobe;* in late afternoon, when relative humidity was the lowest, latent heat of vaporization (evaporative cooling) would exhibit a reverse effect – *adobe would actually cool.* However, the explanation provided by the author centered on what is said to be the 'flywheel effect' – a delayed conduction of temperature change across the wall due to the sheer mass of the wall – a partial but incomplete explanation.

Summary

The preliminary results of a series of ongoing experiments may be summarized as follows:

1. Adobe is indeed cooler in the summer and warmer in the winter, and significantly so, in comparison to cinderblocks and other non-earthen building material. The reason does not relate directly to sensible heat of conduction but rather to latent heat and especially latent heat of vaporization and condensation. Latent heat appears to stabilize internal temperatures within an adobe enclosure.

2. Thermal qualities of adobe and other earthen materials cannot be accurately expressed with the R-value used for conventional building material. The "guarded hot box", used to determine the R-values, is concerned with differential heat on either side of the material being tested where a steady-state heat flow is then measured. However, for adobe, it is the latent heat of vaporization and condensation promoted by a *moisture differential* on either side of a wall of an enclosed adobe building that lowers or raises the temperature of the adobe material. The concept of insulation, as it is applied to conventional building material, is of doubtful use or significance when considering the thermal qualities of an adobe structure.

3. Caution is suggested in the use of any material, modifications or structure that might impede the thermal dynamics of latent heat phenomena of earthen structures.

4. Latent heat phenomena would appear to strongly favor what has come to be known as a "green roof" for adobe structures.

5. Adobe, and similar type material, must be recognized for what it is – a very superior building material both from the standpoint of its functional value and economic consideration. Economically the price of soil is not tied to the price of oil and the utility costs for heating or cooling would be significantly reduced.

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