# COOLING WITH NIGHT AIR

**by Steve Baer**
**Zomeworks**
**1221 Edith NE**
**Albuquerque, NM 87102**

Opening the windows at night and closing them during the day is a traditional way to stay comfortable in an adobe house during the summer in New Mexico.

How big should these windows be, where should they be located and just how much hot weather can you survive with this cooling scheme?

It is easy to make this system work in Santa Fe where the average low in July is 57° F but much more difficult in Albuquerque where the average July low is 62° F and where tropical nights are common. (A tropical night has a low of 68 or above.)

The high temperature is important; it is the condition the house is defending you from, but you find that you would be glad to suffer a 5° temperature rise during the day if the low would sink an extra 3° at night. A good low temperature allows you to weather a bad high.

During the heat of the day you separate the inside of the house form the outside with the insulation in the roof and the walls. The good R values of these surfaces which keep the heat in during the winter will keep the heat out during the summer, especially if you shade the surfaces so that their temperatures don't rise high above ambient. The recent attention to good insulation serves a house well both winter and summer, but the summer problem turns out to be more tricky to deal with passively than the winter.

Heat seeps out during the winter and is replaced by body heat, and other internal and solar gains, but in the summer the heat that seeps in joins the internal gains. They don't balance one another for your benefit. They gang up to make you uncomfortable.

The daily dose of heat gain, sunlight entering windows, heat passing through walls, and internal gains, is absorbed by the house. If the house has large thermal mass and the total gains are relatively small, the house's temperature rise will be small. So far we have discovered that we need a well insulated and well shaded house with small internal gains and large thermal mass. These ingredients alone are not enough to keep cool in the summer. After all, wouldn't a well insulated house run 10° above the average ambient temperature? It will do this to our satisfaction in the winter and if allowed to would do the same in the summer — rising to a fairly steady 90° during Albuquerque's summer warm spell. The secret for summer comfort is to abandon the well insulated condition of the house as soon as it cools off during the night. This was Harold Hay's revolutionary solution to house comfort — moveable insulation.

In many New Mexico climates, a satisfactory change in the house's insulation can be accomplished without moving any large panels of insulation. It can all be done by means of variable ventilation rates: low ventilation rates during the hot day when the outside air entering the house brings with it disagreeable heat, and rapid ventilation rates when the entering air is cooler than the house thermal mass and thus able, by leaving at a higher temperature than it enters, to carry heat away.

### Air Flow and the Open U Value

Consider how we calculate the rate of heat loss in the winter from air changes. One air change an hour in a house with 8′ ceilings is 8 cubic feet per square foot of floor area per hour. A cubic foot of air carries approximately 0.02 BTU/°F. Thus the 8 cubic feet per square foot of floor area would carry away about 0.16 BTU/sq. ft. floor/°F/hr. If the air flow is stated in the more conventional ventilating units cfm (cubic feet per minute) per sq. ft. floor, the rate of heat loss in BTU/sq. ft. floor/°F/hr. can be found by multiplying cfm/sq. ft. floor by 1.1.

We mention this equation even though we will have to modify it for higher flow rates because we intend to disregard all other modes of heat loss at night. The heat leaving through the roof, walls, and windows will be insignificant compared to what is carried away by ventilation.

During most of the year we pride ourselves on constructing a house with a low U value, perhaps as low as .15 BTU/°F/sq. ft. hr., a house that is thermally isolated from the outside. Now we want the house to have a high U value for summer nights. This is the open U value, or Uo. We'd like it to be as high as 1 or 2 — ten times as large as the regular U value. How much air should we move through the house? This is the first question.

My guess is that it should be between 1 and 2 cfm/sq. ft. exposed thermal mass within the house. This is a very high ventilation rate when you consider that a house with a slab floor and interior mass walls may well have 3 sq. ft. of exposed thermal mass/sq. ft. of floor. The proper ventilation rate would be between 3 and 6 cfm/sq. ft. floor or between 20 and 40 air changes an hour. This flow of 1 or 2 cfm/sq. Ft. thermal mass seems appropriate because of the diminishing return as you move more and more air through the building. The air that enters is not guaranteed to leave at the same temperature as the thermal mass. After the ventilation air enters the room to be cooled it must pick up the heat from the thermal mass. The U value between the thermal mass and the slowly moving room air is about 1. There is less and less reward for adding to the flow of air through a room when the heat transfer between the room air and the thermal mass is restricted. Of course, we can attack this restriction by using a ceiling fan within the room to raise the air velocity and thus increase the rate of transfer between it and the thermal mass. A room with a ceiling fan is able to benefit from a larger flow of fresh air than a room without something to stir the air.

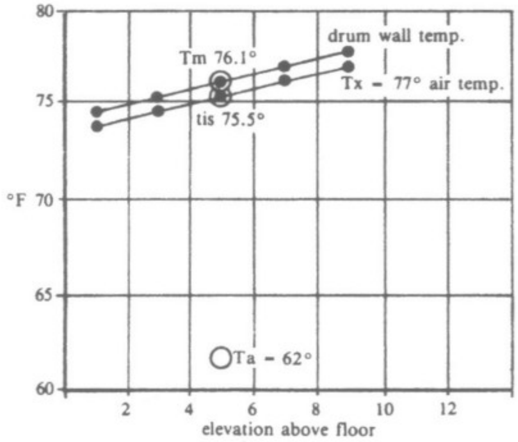
### Temperatures in the Baer House

You can learn a great deal about the ventilation of a room by examining some temperatures and their relationships. The temperatures are the ambient temperature Ta, the exhaust temperature Tx, an average inside air temperature Tis, and an average thermal mass temperature Tm.

If h is the conductivity (film factor) between the inside air and the thermal mass and hv is the carrying capacity of the air flow per square foot (1.1 cfm/sq. ft.), then $h\,(Tm - Tis) = hv\,(Tx - Ta)$ and $\frac{h}{hv} = \frac{Tx - Ta}{Tm - Tis}$

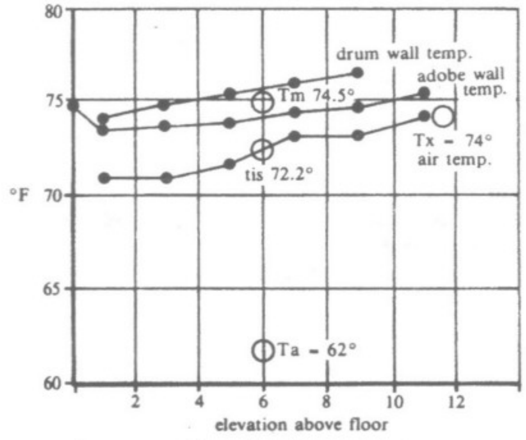
This equation is useful because if you measure TX, Ta and approximate Tm and Tis and find that h/hv is large — say, 3 or more — you know that you can greatly benefit by increasing hv, that is increasing the air flow through the room. The usual case is to find a very high ratio between h/hv. Most buildings are underventilated on summer nights. Graphs 1 and 2 show temperatures and the ratio h/hv for two rooms in my own house on a still morning with only natural convection acting to move air. Notice the huge difference in h/hv. The guest room is miserably ventilated (one ½ sq. ft. vent at the top of the room) with a ratio of 25. The living room has a large 10 sq. ft. vent but could benefit greatly from still more ventilation since the ratio is still high at 5.2.

**GRAPH 1. Baer House Guest room**
**5:30 a.m. — 23 Aug 83**



$$\frac{h}{hv} = \frac{Tx - Ta}{Tm - Tis} = \frac{77 - 62}{76.1 - 75.5} = 25$$

**GRAPH 2. Baer House Living room**
**5:30 a.m. — 23 Aug 83**



$$\frac{h}{hv} = \frac{Tx - Ta}{Tm - Tis} = \frac{74 - 62}{74.5 - 72.2} = \frac{12}{2.3} = 5.2$$

## Calculating $U_O$

An element of internal thermal mass has two resistances in series; 1/h and 1/hv separating it from the outside air. If I wish to calculate $U_O$, I can make some kind of reasonable approximation by assuming that h = 1. Then, because I know h/hv I can calculate hv. For instance, in my guest room h = 1 and hv = 1/25 and in my living room h = 1 and hv = 1/5. The total resistance then is $\frac{1}{1} + \frac{1}{1/25} = 26$ for the guest room and $1 + \frac{1}{1/5} = 6$ for the living room. You might think that these are the reciprocals of the $U_O$ values for the two rooms and that I have the miserable open U values of 1/26 and 1/6. The open U value is calculated per square foot of floor. The wretched U value of 1/26 and the poor value of 1/6 must be multiplied by the number of square feet of surface per square foot of floor. Each room, in addition to adobe walls and slab floor has 25 55-gallon drums, each with 20 square feet of exposed surface. The ratios of exposed thermal mass to floor area, (J) are about 6 in my guest room and 4 in the living room. Multiplying by these factors, I get a very approximate $U_O$ for the guest room of 6/26 = .2 and 4/6 = .7 for the living room.

Once we have a good approximation of $U_O$, we can calculate and do a fairly good job of predicting a building's performance. (See "Concentrating Skylights, Insulation and Ventilation" by Steve Baer, *Home Remedies*, Mid Atlantic Solar Energy Association, 1980).

The difference between the incoming air Ta and the departing air Tx is large compared to the difference between the room air Tis and the thermal mass Tm. Obviously a sluggish air flow is going to allow the air to approach the temperature of the thermal mass and thus slow down the transfer of heat from the thermal mass to the air.

If the air enters the room at Ta and leaves at Tx, then wouldn't the average temperature Tis just be the average of these two tempertures? Look at a building in the winter with a very slow ventilation rate. The incoming air is 25°, the outgoing air is 65°, but the average air temperature is not $\frac{65 + 25}{2} = 45°$. Instead, Tis is very close to 65°. The average temperature Tis does approach $\frac{Ta + Tx}{2}$ if the room is rapidly ventilated, but poorly stirred.

### Natural Ventilation

We now know that we would like to bring 1 or 2 cfm of ventilation air/sq. ft. thermal mass through the house. How are we going to do it? Many books mention placing windows for "cross ventilation" and talk at great length about catching the breeze to cool the house. Such schemes are fine if there is a wind, but a house designed to depend on the wind is a miserable failure when the wind stops. The only sure way to ventilate a house is to use natural convection or to use exhaust fans.

Exhaust fans or whole house fans, as they are called, are well worth the power they consume when you consider the cooling they provide, but their noise is irritating and it is still cheaper to use natural ventilation.

The equation for natural ventilation in the ASHRAE handbook can help size the vents.

$$V = 9.4 \sqrt{(t_i - t_a) E}$$

*Where* V is the velocity in ft./min, ti is the temperature averaged over the different elevation between the entrance and the exit. ta is the ambient temperature and E is the difference in elevation between the entrance and the exit.

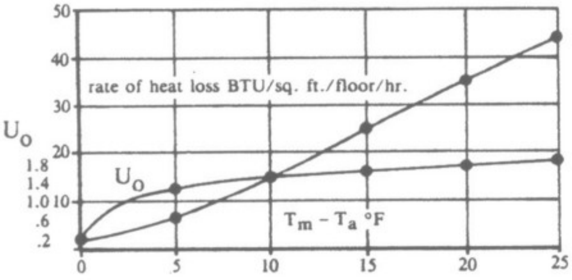
If we assume that the inlet vents are at floor level and the exit vent 10′ above and the average temperature inside is 10°F above ambient, we have

$$V = 9.4 \sqrt{10 \cdot 10} = 94 \text{ ft./min.}$$

What if a 300 sq. ft. room has 3 sq. ft. of thermal mass for each sq. ft. of floor and it is to be ventilated at 1.5 cfm/sq. Ft. of thermal mass? [300 × 3 × 1.5 = 1350 cfm.] To get this much ventilation at 94 ft./min., entrance and exit vents need to be $\frac{1350}{94} = 14.4$ sq. ft. The simple assumption allowed an easy answer. Below is Graph #3 with two curves on it showing the rate at which a room will cool itself by natural ventilation. The properties of the room are listed below the graph. R, shape factor, is the one unfamiliar term. R = .5 if the thermal mass were all in the walls. $(t_i - t_a) = R(t_x = t_a)$ The graph was drawn by repeated solutions to the equation:

$$(\sqrt{t_x - t_a})^3 + \frac{J_h (\sqrt{t_x - t_a})^2}{10.3 \times RE} - \frac{hJ(t_m - t_a)}{10.3 \times \sqrt{RE}} = 0$$

**GRAPH 3. Rate of Cooling for simulated room**



Properties of Room:

| | | |
|---|---|---|
| $X_1$ | vent area/floor area | .04 |
| R | shape factor | .7 |
| E | elevation difference between vents | 9′ |
| J | thermal mass area/floor area | 3 |
| $T_a$ | ambient temperature | variable |
| $T_m$ | thermal mass temperature | 75° |
| h | U factor, thermal mass to inside air | 1 |

The curve that rises quickly then levels shows the open U value of the building. It rises quite quickly to about 1 as the ambient temperature drops below the temperature of the inside thermal mass. Even small temperature differences create good thermal contact between the room and the outside. The other curve starts more slowly, but becomes steeper and steeper. It shows the rate of heat loss/sq. ft. floor. This second curve which bends upwards demonstrates that our natural ventilation scheme works best after you no longer need it.

Consider the sample house in Santa Fe with thermal mass at 75° and outside air at 60°. It is losing heat at 25 BTU/sq. ft./hr. while the same house in Albuquerque with outside air at 70° would be disposing of only 5 BTU/sq.ft./hr.

Passive cooling by ventilation is a frustrating business after dealing with the simpler passive heating, but it is worth utilizing over most of the country for at least part of the year.

I understand that the DOE is contracting LASL to do a study of cooling with night air. I expect we will receive the familiar computer generated curves and confident assertions about performance from the LASL group. What I don't understand is how they were able to publish so many reports about passive buildings, spend so many millions of dollars and give such self-confident advice about the design of buildings without ever including the subject before. My own theory is that the DOE continues to spend money for solar research at the weapons labs because it uses the solar work as a deodorant. A little of the especially fragrant "Passive Solar Program" sprinkled on LASL makes the lab more acceptable to the public who is horrified by nuclear bombs.

***Acknowledgement:*** I would like to thank Michael Zeiler for doing the computer calculations for Graph #3.