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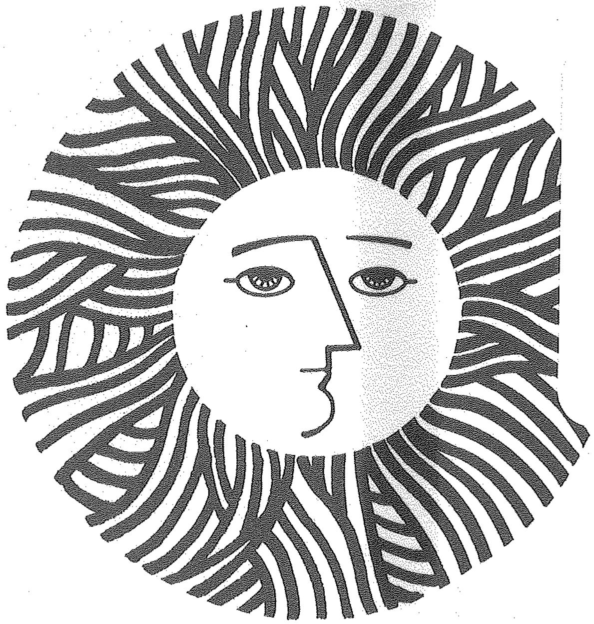

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INCREMENTAL COOLING LOAD DETERMINATION FOR PASSIVE DIRECT GAIN HEATING SYSTEMS*

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ABSTRACT

This paper examines the applicability of the National Association of Home Builders (NAHB) "full load compressor hour" method for predicting the cooling load increase in a residence, attributable to direct gain passive heating systems. The NAHB method predictions are compared with the results of 200 hour-by-hour simulations using BLAST and the two methods show reasonable agreement. The degree of agreement and the limitations of the NAHB method are discussed.

1. INTRODUCTION

Currently used methods of calculating passive direct gain heating system performance do not account for increases in the building cooling load resulting from increased south aperture areas. Since this increase means more non-renewable energy (air conditioning) must be used to remove the excess summertime heat, it is necessary to include cooling energy when calculating the net value of the passive direct-gain system. This would take the form of a performance penalty, with the magnitude of passive system heating savings reduced by the amount of increase to the cooling load.

Intuitively, one sees that the effect of this penalty will vary from region to region. In far southern areas, where cooling loads are more significant than heating, the cooling penalty cancels out any benefits from region to region. In far southern areas, where cooling loads are more significant than heating, the cooling penalty cancels out any benefit from direct gain heating and little, if any, direct gain aperture is recommended. In northern climates, the cooling penalty is insignificant compared to heating benefits, and so has little or no effect on recommended direct gain aperture. In-between regions are most affected for large aperture, direct gain systems, where the cooling penalty is most significant; in this case, the optimal passive aperture should not increase beyond moderate size.

The only reliable methodology for examining such increases in cooling due to passive systems has been to utilize large detailed hour-by-hour simulation programs. Such programs are not available to many practicing designers and if available are generally too expensive and burdensome to utilize in residential design. More importantly, simple procedures, such as the Solar Saving Fraction method, are used predominantly for predicting passive system reductions in heating auxiliary, and it is very desirable to have a comparably simple method for examining cooling loads.

Such a simple method has been used by the National Association of Home Builders (NAHB) for determining annual cooling loads in conventional buildings; it is known as the "full load compressor hour" method. This paper compares the cooling load increases predicted by the NAHB method with the increases predicted by hour-by-hour simulations utilizing the computer program BLAST.[‡]

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[§] Total Environmental Action, Inc., Harrisville, NH, 03450.

[‡] Building Loads Analysis and System Thermodynamics. BLAST is copyrighted by the Construction Engineering Research Laboratory, U.S. Department of the Army, Champaign, Illinois.

2. DESCRIPTION OF CALCULATION METHODS

2.1 NAHB Full Load Compression Hour Method

The NAHB full load compressor hour method is based upon a calculation procedure which utilizes radiant, conductive, and infiltration heat gain through windows, latent heat gain and cooling system capacity multipliers, and the annual number of equivalent, full load cooling compressor hours for each location. In its simplest form, the incremental cooling load (CL) due to direct gain windows can be expressed as:

$$CL = H \times Q \times A$$

where

H = the number of equivalent full load operating hours per year per square foot of aperture (available from NAHB data)

Q = heat gain value for a specific window orientation and shading type ($MMBtu/ft^2$-hr)

A = window area under consideration (ft^2).

The equivalent full load operating hours and heat gain values are given for representative locations (typically 5 to 10 locations per state) in the publication Insulation Manual: Homes and Apartments [1], available from the NAHB Research Foundation.

The operating hours are on NAHB data for 1000 zip code cities. This data was developed from temperature bin data supplied by approximately 150 utility companies.

Although the heat gain value is used in the above as a single value, it may be expressed as:

$$Q = (q_1 + q_2 + q_3) \times F_L \times F_C$$

where

q_1 = radiant heat gain through the appropriate glazing configuration ($MMBtu/ft^2$-hr)

q_2 = window conductance gain ($MMBtu/ft^2$-hr)

q_3 = infiltration heat gain for windows ($MMBtu/ft^2$-hr)

F_L = latent heat load factor (dimensionless)

F_C = capacity multiplier factor (dimensionless).

The calculation of the radiant, conductive, and infiltration heat gains are based on methods in the ASHRAE Fundamentals [2]. The latent heat load factor (F_L) is given as 30% of the direct heat gain. Further correction for regions with higher levels of humidity is made in the capacity multiplier factor, F_C, which reflects the difficulty of cooling; it is derived from Manual J of the National Environmental Systems Contractors Association (NESCA)[3]. Three climatic characteristics are accounted for: daily outside temperature swing, dry bulb temperature for the 1% summer design condition, and humid regions with latent loads greater than 30%. The capacity multipliers assume a 3°F inside temperature swing, thus allowing a room with a thermostat set point at 75°F to reach 78°F. A summary of the capacity multipliers (F_C) is given below:

TABLE 1

1% Summer Design Temp. (Dry Bulb)	Daily Temp. Swing Outside	Capacity Multipliers F_C
90°F	15 to 25°F	0.97
95°F	25+ °F	1.02
95°F	15 to 25°F	1.03
100°F	25+ °F	1.08
100°F	15 to 25°F	1.09
105°F	25+ °F	1.22

The table illustrates that the capacity multiplier increases as the dry bulb temperature increases. At one dry bulb temperature, lower temperature swing gives a larger capacity multiplier. In humid regions with a latent load greater than 30%, one chooses the next highest capacity multiplier (approximately 10% increase).

The NAHB full load compressor hour method was used to calculate the incremental cooling effects of adding an increment of 1 ft^2 to a passive building in each of the 25 locations given in Table 3. The NAHB method gives a constant incremental cooling load per square foot of glazing regardless of whether the square foot is the first square foot or the thousandth square foot. The heat gain values selected were for south facing double glazing with an exterior shade (no beam solar radiation) as would be standard practice in a passive building.

2.2 BLAST Calculation Method

The model selected for comparison with the NAHB method is the public domain building energy analysis computer program, BLAST. BLAST is capable of hour-by-hour modeling of building thermal dynamics including features of particular interest, such as passive aperture area, shading, thermostat set point, latent loads, and forced ventilation (economizer cycles).

Unlike the NAHB cooling method which is independent of building configuration, the BLAST simulations require detailed building specifications. The building modeled is a 109 m^2 (1176 ft^2) single story ranch style home. Basic parameters are given in Table 2 and thermal insulation values by city are given in Table 3.

Cooling loads at zero south aperture and at 24.5 m^2 (264 ft^2) south aperture were calculated. The incremental cooling load per unit area was then determined.

TABLE 2. BLAST Parameter Schedule (Ranch House)

SLAB (Ground Contact (Area)	109 m^2	1176 ft^2
WALL AREAS		
Front		
• Insulation Area (75% of net wall area)	18	196
• Stud Area (25% of net wall area)	6	65
• Window Area	5	55
• Door Area	2	20
	31 m^2	336 ft^2
Rear		
• Insulation Area (75% of net wall area)	18	198
• Stud Area (25% of net wall area)	6	66
• Window Area (including single-glass door)	7	72
	31 m^2	336 ft^2
Sides		
• Insulation Area (85% wall area)	18	190
• Stud Area (15% wall area)	3	34
	21 m^2	224 ft^2
Ceiling		
• Insulation Area (90% floor area)	98	1058
• Truss Area (10% floor area)	11	118
	109 m^2	1176 ft^2
THERMOSTAT (Summer)	25°C	77°F
Ventilate in Summer When Possible Down to Temp:	21°C	70.5°F
Fixed Shading Overhang	.6 m	2 ft

3. RESULTS

The incremental cooling loads per square foot of glazing for both the NAHB method and the BLAST simulations for 25 cities is plotted in Fig. 1 (not all locations are labeled). As is apparent from Fig. 1, reasonably consistent results are obtained between the two methods.

4. DISCUSSION

The reasonable agreement between the detailed and simple methods is compelling. Although such a simple method as the NAHB method can clearly benefit from continued refinement, the agreement is believed adequate for design decisions appropriate to the Solar Savings Fraction method for heating.

The most significant discrepancies occur for those locations with high incremental cooling loads such as the humid Gulf Coast area. However, even though the NAHB method underestimates the amount of cooling required, the increased cooling load is sufficient to preclude the cost-effective use of passive direct gain systems in those areas. The more accurate predictions using BLAST only serve to increase the apparent penalty for using passive systems in these areas.

The results presented are for incremental cooling loads of the building and do not account for system efficiencies. Therefore, when adjusting heating performance and cooling performance, it is necessary to consider equipment efficiencies for both modes before determining the net energy impact of the passive system.

Although the NAHB method shows promise as a tool for estimating incremental cooling loads, care should be taken in applying these results in actual design practice. The incremental cooling impact of a unit area of aperture is dependent on the total building heat loss coefficient (as shown in detailed BLAST runs not presented in this paper). The actual cooling impact may vary significantly for a building substantially different from that described in Section 2.2. Furthermore, although ventilation was considered in this investigation, other user interactions, such as using movable insulation during peak cooling conditions, were not considered. The use of movable insulation is not necessarily considered appropriate, however, due to assumed occupant desires for daylighting. Although not specifically investigated, it may be possible that the use of movable insulation can be analyzed through the use of conventional UA calculations neglecting beam, diffuse and reflected insolation.

5. CONCLUSIONS

The NAHB full load compressor hour method is shown to provide a first order approximation of the average cooling loads determined by the building thermal simulator, BLAST. The simplicity of the NAHB method, and the reasonable agreement with the BLAST simulations,

TABLE 3.

	INSULATION R-VALUE			
LOCATION	GLAZINGS	WALL	CEILING	FLOOR SLAB
Albuquerque, NM	2	R19	R38	R10
Apalachicola, FL	2	R19	R38	R10
Bismarck, ND	2	R25	R38	R10
Boston, MA	2	R25	R38	R10
Brownsville, TX	2	R19	R38	R10
Cape Hattaras, NC	2	R19	R38	R10
Caribou, ME	2	R25	R38	R10
Charleston, SC	2	R19	R38	R10
Columbia, MO	2	R25	R38	R10
Dodge City, KA	2	R25	R38	R10
El Paso, TX	2	R19	R38	R10
Ely, NV	2	R25	R38	R10
Fort Worth, TX	2	R19	R38	R10
Fresno, CA	2	R19	R38	R10
Great Falls, MT	2	R25	R38	R10
Lake Charles, LA	2	R19	R38	R10
Madison, WI	2	R25	R38	R10
Medford, OR	2	R25	R38	R10
Miami, FL	2	R19	R38	R10
Nashville, TN	2	R19	R38	R10
New York, NY	2	R25	R38	R10
Phoenix, AZ	2	R19	R38	R10
Santa Maria, CA	2	R19	R38	R10
Seattle, WA	2	R25	R38	R10
Washington, DC	2	R25	R38	R10

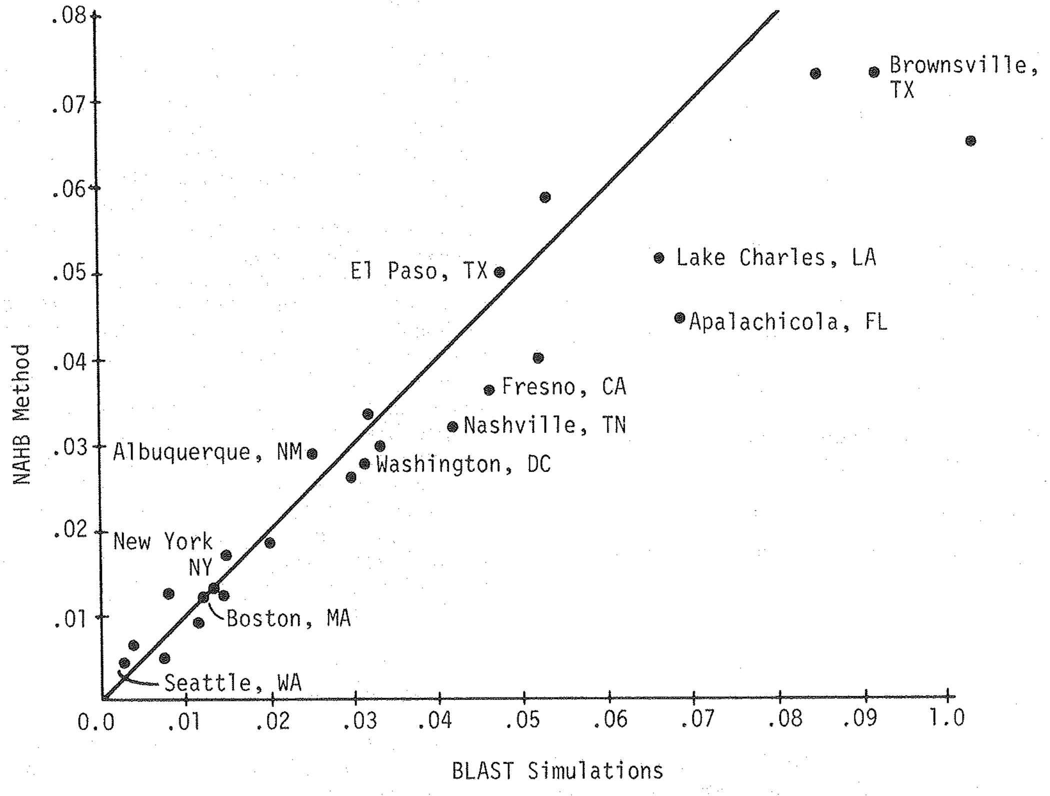

FIGURE 1. Average Incremental Cooling Load from South Aperture (Shaded) (MMBtu/ft^2 Glazing)

provides a compelling argument for adjusting the net thermal benefit of passive direct gain systems. Designers must exercise considerable judgment, however, in determining the actual degree of shading and the influence of occupant interactions such as the use of movable insulation during daylight hours.

As illustrated by the results discussed, the net performance of direct gain passive systems is significantly impacted by cooling considerations, and a more rigorous, yet simple method of calculating cooling impacts will provide needed information to designers. Such work is strongly encouraged.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

1. Insulation Manual: Homes and Apartments, NAHB Research Foundation Inc., 627 South Lawn Lane, P.O. Box 1627, Rockville, MD 20850, 2nd edition.

2. ASHRAE Handbook & Product Directory, 1977 Fundamentals, American Society of Heating, Refrigeration, and Air Conditioning Engineers Inc., 345 East 47th St., New York, NY 10017.

3. Manual J, Load Calculations for Residential Winter and Summer Air Conditioning, Air Conditioning Contractors of America, 1228 17th Street, NW, Washington, D.C. 20036.