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ENERGY BUDGETS AND MASONRY HOUSES: A PRELIMINARY ANALYSIS OF THE COMPARATIVE ENERGY PERFORMANCE OF MASONRY AND WOOD-FRAME HOUSES

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ABSTRACT

Energy Performance Standards require the establishment of energy budgets - maximum values of predicted building energy consumption assuming standard building operating conditions. Energy budgets based on minimizing life-cycle-costs to consumers have been computed in earlier reports. The prototype buildings for those studies used wood-frame construction.

The energy performance of masonry houses is explored in this paper. Theoretical aspects of the modelling of masonry buildings on the DOE-2 program are discussed. Results of DOE-2 simulations are presented. Energy budgets which correspond to cost-minimizing masonry houses are found to be approximately equal to those for frame houses. The same energy performance requires only slightly less insulation in masonry walls than in frame walls for the climates studied. It is concluded that separate energy budgets for frame and masonry houses do not appear to be warranted.

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INTRODUCTION

Masonry buildings have a greater ability to store heat than wood-frame houses, and their structure presents different technical and economic criteria for insulating their walls. These considerations raise several issues regarding the compliance of masonry buildings with building energy performance standards. The primary issues are:

1. Will the procedure for evaluating energy performance properly account for the effect of heat storage?
2. Will a masonry house be able to comply with energy budgets in a cost effective manner?

The first issue revolves around the method used to evaluate compliance. The budgets established by the U.S. Department of Energy[1] were based on modelling houses on the DOE-2 program.[2] This program accounts for the dynamic heat transfer properties of building elements, so any beneficial (that is, energy-saving) features of masonry houses will be reflected in their design energy consumption estimates if the DOE-2 program is used to demonstrate compliance. Simpler methods, such as those based on design heat loss,[3] will not capture this effect, and adjustments will have to be made in the compliance procedure if these methods are employed.

The second issue addresses the methodology by which the standards were devised;[4,5] it asks whether the same methodology, applied to masonry buildings, will give comparable results. The residential energy performance standards were derived by minimizing life-cycle costs using a prototype house. Masonry houses are one example of buildings which have features that do not resemble those of the prototype. The life-cycle cost minima for these buildings may be different from those derived for the prototypes. Conceivably, the cost curves have a different shape, and meeting the "optimum" budgets may be infeasible for a masonry house.

The difference in energy and economic performance between the prototype (wood-frame) houses on which the energy budgets were based and masonry buildings can be expressed in terms of two questions:

1. How can masonry houses conform to the "optimum" budgets? What insulation levels and costs are needed for compliance?
2. What are the life-cycle cost-minimizing energy budgets for masonry houses? How do they compare with the (wood-frame) "optimum" budgets?

SUMMARY OF METHODOLOGY AND RESULTS

The analysis is performed by using the DOE-2 computer program to model a prototype masonry house in several climates. The prototype resembles the LBL single story house,[5] except that the walls are made of concrete block. We use the same specifications for the concrete block as Petersen.[6] We assume that partition walls are also made of masonry, and that a slab on grade floor is used.

Our base case house has no wall insulation; it simply uses drywall inside the concrete blocks. Insulation measures for the other elements of the house correspond to those in the "optima." Wall insulation steps are successively added, and life-cycle costs computed using the usual BEPS methodology and economic assumptions.[4,5]

The results so far are preliminary, but we believe them to be substantially correct. To the extent that there are errors, we expect them to be on the "conservative" side - that is, that the final results will show even less difference between frame walls and masonry walls than the results presented here.

The results can be summarized by the answers to the two performance questions posed above. First, to conform with the "optimal" energy budgets, masonry walls must be insulated to almost as large an R-value as frame walls. Thus, if the optimal wood frame house has R-19 walls, the masonry house will require almost (but not fully) R-19 of insulation. Since the optima always involve at least R-11 insulation, masonry walls will also require almost R-11 of insulation. Uninsulated masonry walls will result in energy performance significantly worse than the (insulated) frame-walled house. Figures 1-5 present these results graphically, plotting whole house heating and cooling requirements as a function of wall conductance for both masonry and frame walls. As seen, heating and cooling depend quite linearly on wall conductance, with the lines for masonry and frame very close to each other.

It further appears that insulating masonry houses to these levels is cost effective even in warm climates such as Ft. Worth and Phoenix. Insulation techniques which involve interior furring and ordinary mineral wool insulation are the cheapest, given our cost data.

Second, the optima for a masonry prototype would be comparable to those for a frame house. For most climates, the masonry optima are slightly lower (in energy use) than the frame optima;[6] because the optimum insulation has the same R-value as in the frame house but masonry buildings use slightly less energy for a given insulation level than frame houses.

We conclude that, since the differences in energy performance curves between frame and masonry buildings is not large, there is no reason to establish a separate energy budget for masonry buildings. If masonry buildings are designed to meet the optimum budgets for frame houses, they will be close to their own life-cycle cost minima.

Even if the departures from official cost minimization (based on frame houses) were larger, one could still argue that separate energy budgets are not needed. The essence of the performance standard concept is that all houses must meet the same energy standard for a given size of house. This uniform energy standard will not, in general, correspond to the cost-minimizing configuration for any given house. It is only when the departures from cost-minimization become large that special exemptions from the general performance standard are advisable. Otherwise, every home which did not exactly follow the prototype specifications (e.g., houses without southern exposure, houses with large view windows, houses with open-beam ceilings, etc.) would seek exemptions; and the standard would become more arbitrary and difficult to enforce.

This potential problem of large differences from the prototype does not occur with masonry buildings. Both our results and those of Petersen[6] show that masonry walls of a given U-value cause a house to perform only a few percentage points better than frame walls of the same U-value. (Petersen shows that insulated masonry is generally not cost-effective, but his report confines itself to insulation strategies which are expensive compared to interior furring and fiberglass insulation.)

RESULTS

We next present our preliminary results in more detail. We consider the following insulation measures for masonry walls: R-11 interior insulation using 2x3 furring, R-19 interior insulation with 2x6 furring, R-6.5 and R-13 exterior insulation with stucco siding, and as an alternative base case to "no insulation," a reflective-foil-backed drywall board (with an assumed reflectivity of 80%). The costs are given in Table I, based on NAHB/RF data supplied by AIA/RC. These are the net costs of each measure in 1980 dollars. "Net costs" means that the cost of ordinary furring which is used in the uninsulated prototype is substracted from the cost of measures involving furring.[7-8]

We look at the cost effectiveness of various combinations of insulation in Tables 2 A-D, for 4 climates, three in the South or Southwest and one cold climate. We compare R-11 and R-19 interior insulation to the base (uninsulated) case. We next compare R-11 to the alternate base case of reflective foil-backed dry-wall. Finally, we compare exterior (foam-board) insulation to the base case, under two assumptions: the case where exterior wall finish is going to be provided in any event, and the second where the cost of an exterior finish of stucco is part of the cost of insulation. Note that in the second case, exterior insulation is almost never cost-effective for gas heat.

Reliability of the Results

In all previous BEPS studies, we have used at least two simulation model results, and compared them. We accepted DOE-2 results when they agreed with those of other programs (generally TWOZONE[9]) or when we felt we understood the reasons for the differences.

For frame houses, the agreement between TWOZONE and DOE-2 is generally good, as discussed in Ref. 10. We have also obtained good agreement between the programs on the comparison between frame and masonry walls. Both programs show the extra heating energy required for R-11 masonry walls compared to R-19 frame to be the same, within about ± 10%.

This agreement is significant, because the approximations involved in the DOE-2 weighting factors, which affect the results described in this report, are not present in TWOZONE. The weighting factors account for the heat storage effects of the thermal mass in the interior of the building including the effects of heat storage on the inside surface of the envelope walls. Weighting factors for DOE- 2.0A are available for only three classes of building: light, medium, and heavy. We used the "medium-weight" weighting factors in the frame house to account for the heat storage in walls and furniture along with envelope walls. For the masonry house, we use "heavy" weighting factors. While these may be justified for exterior-insulated masonry, interior insulation reduces the heat storage effectiveness of masonry substantially.[11,12,13]

The masonry house being modelled has drywall and a dead-air space between the masonry and the room in the "uninsulated" case. Most of the insulated cases place even more insulation between the concrete and the room. This inside insulation greatly reduces the effect of masonry on damping indoor temperature swings and on delaying the influence of solar heat again through the windows. But these are the effects calculated by the weighting factors. Thus, our inside-insulated masonry buildings may not perform as well as the models indicate, particularly if the partition walls are frame and the floors are carpeted.

To test the sensitivity of the results to weighting factors, we ran the R-19 wall masonry house for Fort Worth with the "medium wieght" weighting factors. Heating loads increased by 5% compared to the "heavy" weighting factors, and cooling loads increased by 1.5%. The predicted cost-effectiveness of the insulation decreased slightly, but the optimum did not shift. In this case, the masonry house was predicted to use 98% of the heating energy of the frame house.

The sensitivity of results to weighting factors can also be seen by using the comparisons with TWOZONE. TWOZONE calculates delays in solar heat gain through weighting factors, but calculates indoor temperature swings directly from the building envelope thermal characteristics. We found that changing the solar weighting factors significantly has a relatively small effect on heating loads, even in sunny, warm climates such as Phoenix. So that fact that TWOZONE agrees with DOE-2 on the relative performance of masonry and frame houses shows that the errors introduced by the approximations in the weighting factors do not affect the broad conclusions obtained in these preliminary results.

As a further check on the physical interpretation of the "heavy" weighting factors, we ran one case with no drywall and with exterior insulation for which special weighting factors derived specifically for the prototype were inserted. Results differ from those generated by the "heavy" weighting factors by much less than 1%. Thus, we can interpret the "heavy" results to be the numbers appropriate for a house with bare or exposed concrete walls. However, we used them to represent houses with interior insulation, so our results tend to overstate the difference between masonry and frame buildings. A real house with drywall and/or insulation inside would consume somewhat more energy than the estimates presented here. The "medium" weighting factor test provides an upper bound to energy use.

Future Research

The version 2.1 of DOE-2 has the option of generating custom weighting factors based on the detailed thermal description of a room. We plan to repeat these experiements with custom weighting factors, both for the frame house and the masonry house, to check the accuracy of these preliminary results. We also plan to extend the discussion to warmer climates, such as those of Florida.

CONCLUSIONS

There appears to be no need to establish separate energy budgets for masonry buildings, since it is cost-effective for masonry buildings to comply with the frame-house-based energy budgets. Life-cycle-cost-minimizing energy budgets for masonry houses would not substantially differ from those for frame houses; and in most cases they would be stricter (lower) than the existing design energy budgets.

The detailed evaluation procedure, using the DOE-2 program, will give credit to masonry construction when it is conserving energy relative to a frame house with equal design heat loss. If simplified evaluation procedures based on conventional design heat loss methods are used, masonry buildings will not get proper credit for energy saving. New methods need to be developed for this application. However, the error introduced by failure to provide credits will not be very large: that is, it will not be sufficient to allow the general use of uninsulated concrete block walls in place of insulated frame walls.

Table 1

Cost of Masonry Insulation Measures

Measure	Cost per Gross Square Foot of Wall[a]	Total Option Cost[a]
1 x 3 furring	$ .11	
Reflective foil for gypsum board	$ .106[b]	
2 x 3 furring with R-11 insulation	($ .319)	
Net cost of R-11 measure (compared to 1 x 3 furring)	$ .209	$234
2 x 6 furring with R-19	$ .517	
Additional cost relative to R-11	$ .198	$221.80
1" polyurethene insulation (R-6.5)	$ .55	$616
2" polyurethene (R-13)	$1.056	$1183
2" polyurethene plus stucco	$2.45	$2747

a) In 1980 dollars. NAHB data (see Ref's. 7 and 14) for 1979 are escalated using a factor of 1.1; 1978 costs are escalated by a factor 1.18.

b) Source: Petersen (Ref. 6).

Table 2A

Cost Effectiveness of Masonry Insulation - Gas Heat

Ft. Worth Option	Heating Energy (of Btu/yr)	Cooling Energy (kWh/yr)	Present* Value of Fuel Saved	Benefit/Cost* Ratio of Measure
No insulation	28.471	3074		
R-11 inside	12.991	2611	$ 324	9.74
R-19 inside	10.856	2539	$2278	1.46
R-19 inside and R-13 outside	9.393	2474	$ 240.6	0.20/0.09[a]
Reflective Foil	22.733	2907		
R-11 inside	12.991	2611	$1439	12.51
No insulation	28.471	3074		
R-6.5 outside	15.03	2649	$2005	2.34/0.66[a]
R-13 outside	12.009	2560	$443	0.78

[*] Present value and benefit/cost ratio of the option listed is the difference between that option and the option on the next line above it.

a) Includes the cost of stucco.

Table 2B

Cost Effectiveness of Masonry Insulation - Gas Heat

Phoenix Option	Heating Energy (of Btu/yr)	Cooling Energy (kWh/yr)	Present* Value of Fuel Saved	Benefit/Cost Ratio of Measure[c*]
No insulation	11.047	4741[b]		
R-11 inside	3.614	3790	$1961	8.38
R-19 inside	2.680	3650	$ 271	1.22
Reflective foil	8.234	4396[b]		
R-11 inside	3.614	3790	$1237	10.76
No insulation	11.047	4741[b]		
R-13 outside	3.167	3703	$2114	1.79/0.77[a]

*Present value and benefit/cost ratio of the option listed is the difference between that option and the option on the next line above it.

a) Includes the cost of stucco.

b) Uses the standard 1½ ton air conditioner; for this option the air conditioner is undersized and the house overheats; energy use is artificially low.

c) Using national average insulation prices. Phoenix prices are about 15% higher.

Table 2C

Cost Effectiveness of Masonry Insulation - Gas Heat

Atlanta Option	Heating Energy (of Btu/yr)	Cooling Energy (kWh/yr)	Present Value of Fuel Saved*	Benefit/Cost Ratio of Measure*
No insulation	37.736	1261		
R-11 inside	18.077	1158	$2316	9.89
R-19 inside	15.373	1149	$ 312	1.41
Reflective foil	30.410	1211		
R-11 inside	18.077	1158	$1439	12.51
No insulation	37.736	1261		
R-13 outside	16.823	1130	$2489	2.10/.91[a]

*Present value and benefit/cost ratio of the option listed is the difference between that option and the option on the next line above it.

a) Includes the cost of stucco.

Table 2D

Cost Effectiveness of Masonry Insulation - Gas Heat

Chicago Option	Heating Energy (of Btu/yr)	Cooling Energy (kWh/yr)	Present Value of Fuel Saved *	Benefit/Cost Ratio of Measure *
Base Case R-11 insulation	51.866	600		
R-19 insulation inside	46.080	601	$644	2.90
R12 outside and $-19 inside	42.359	591	$427	0.36/0.16[a]

*Present value and benefit/cost ratio of the option listed is the difference between that option and the option on the next line above it.

a) Include the cost of stucco

Figure 1.

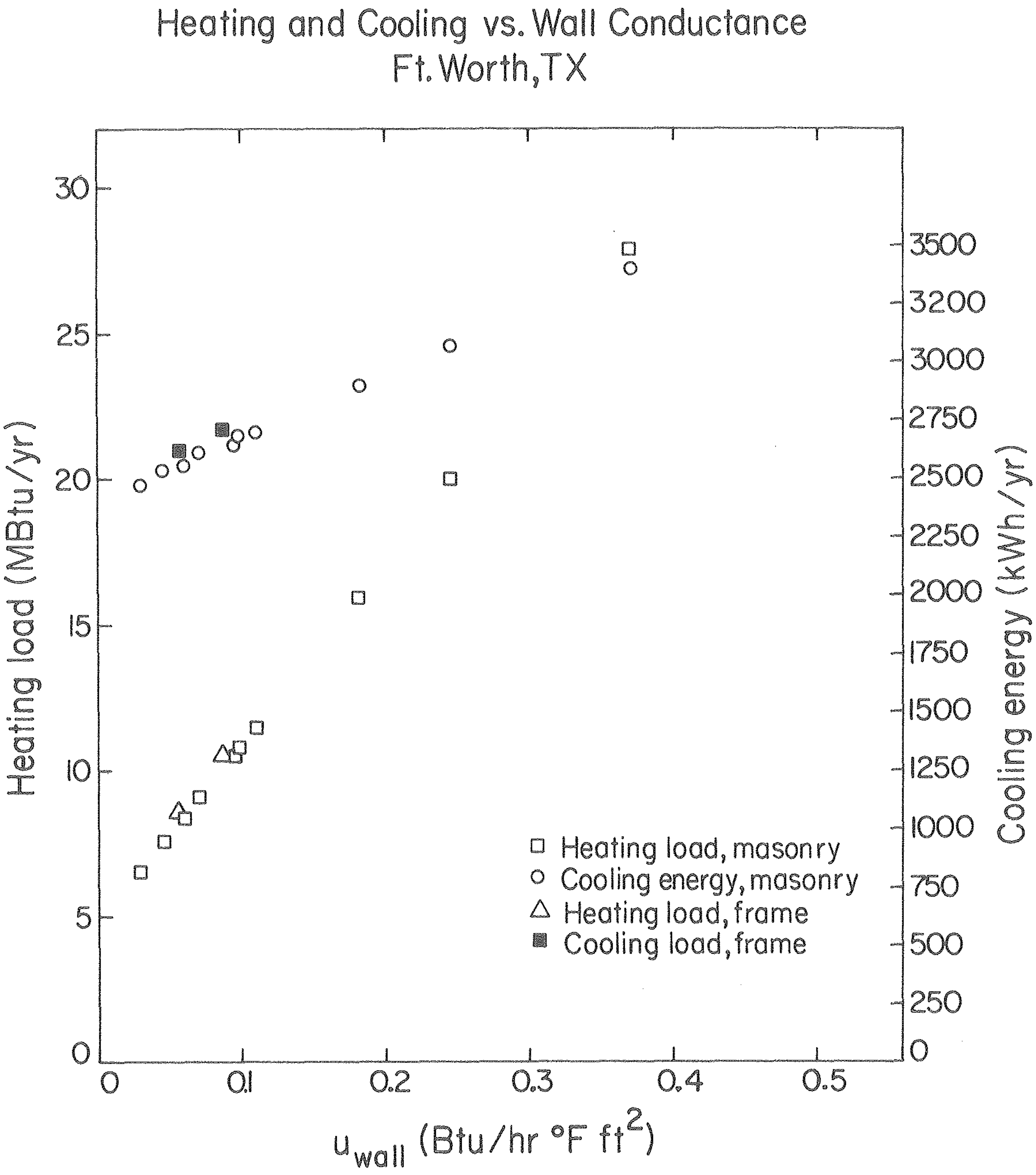

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Figure 2.

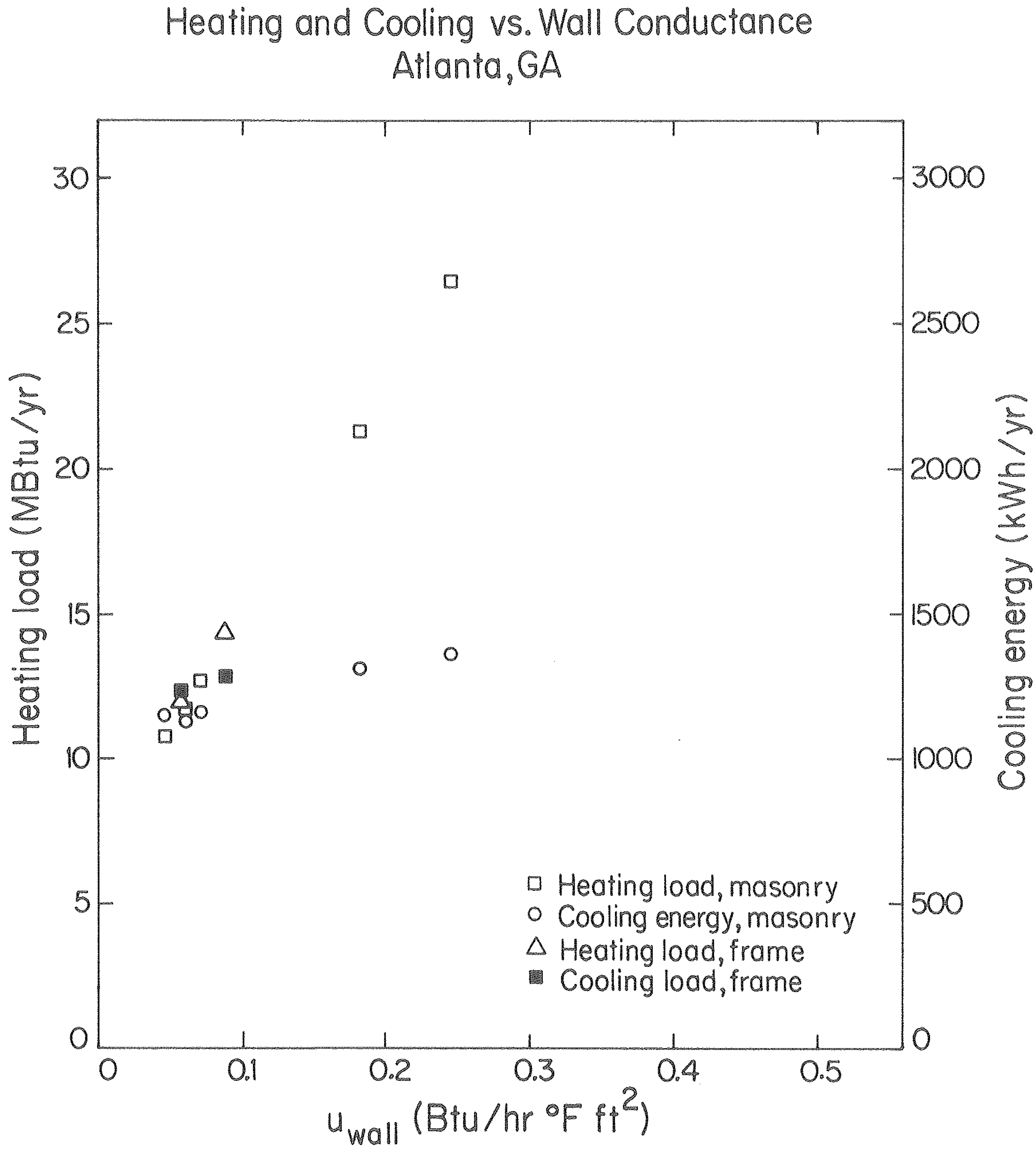

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Figure 3.

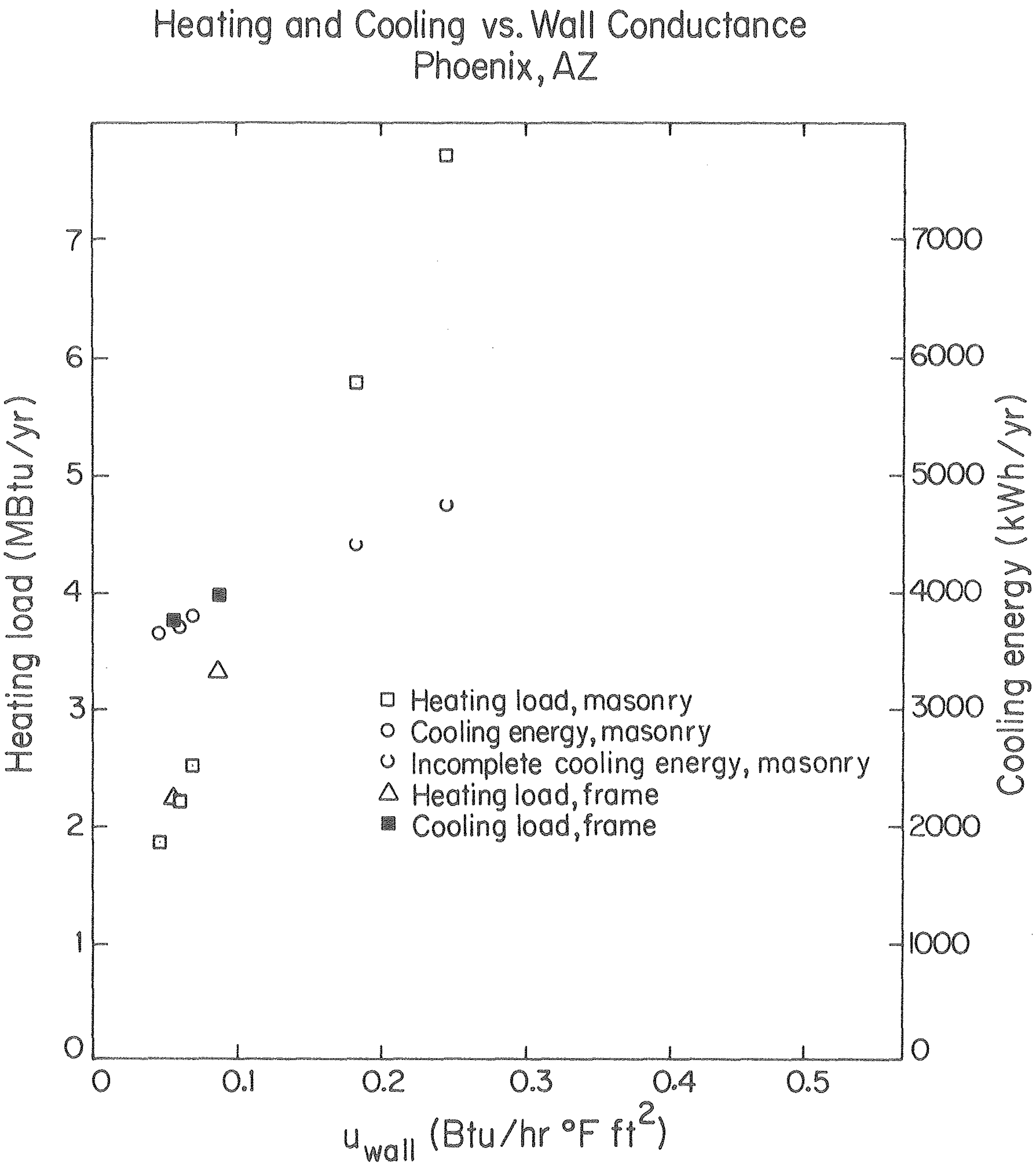

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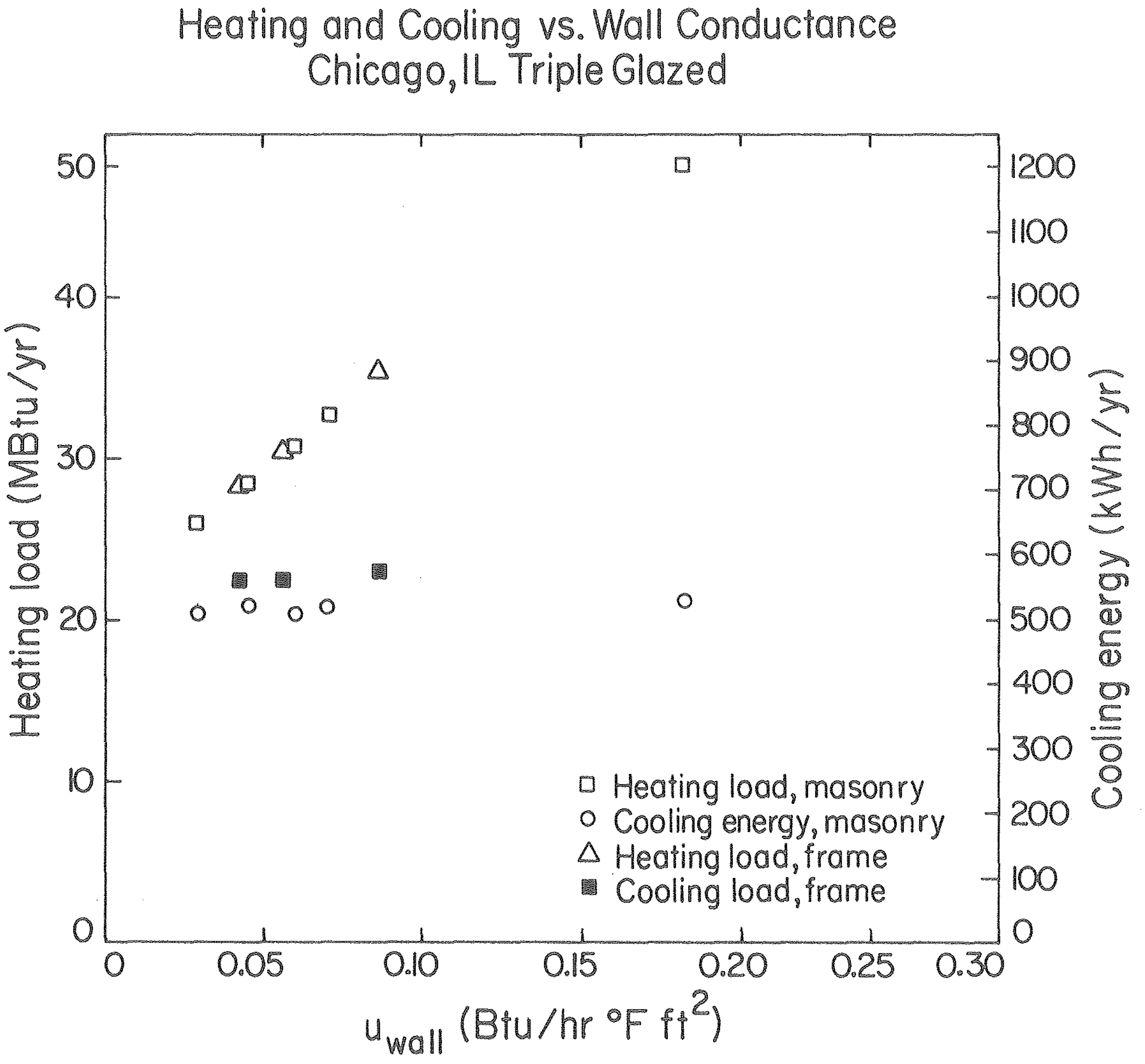
Figure 4.



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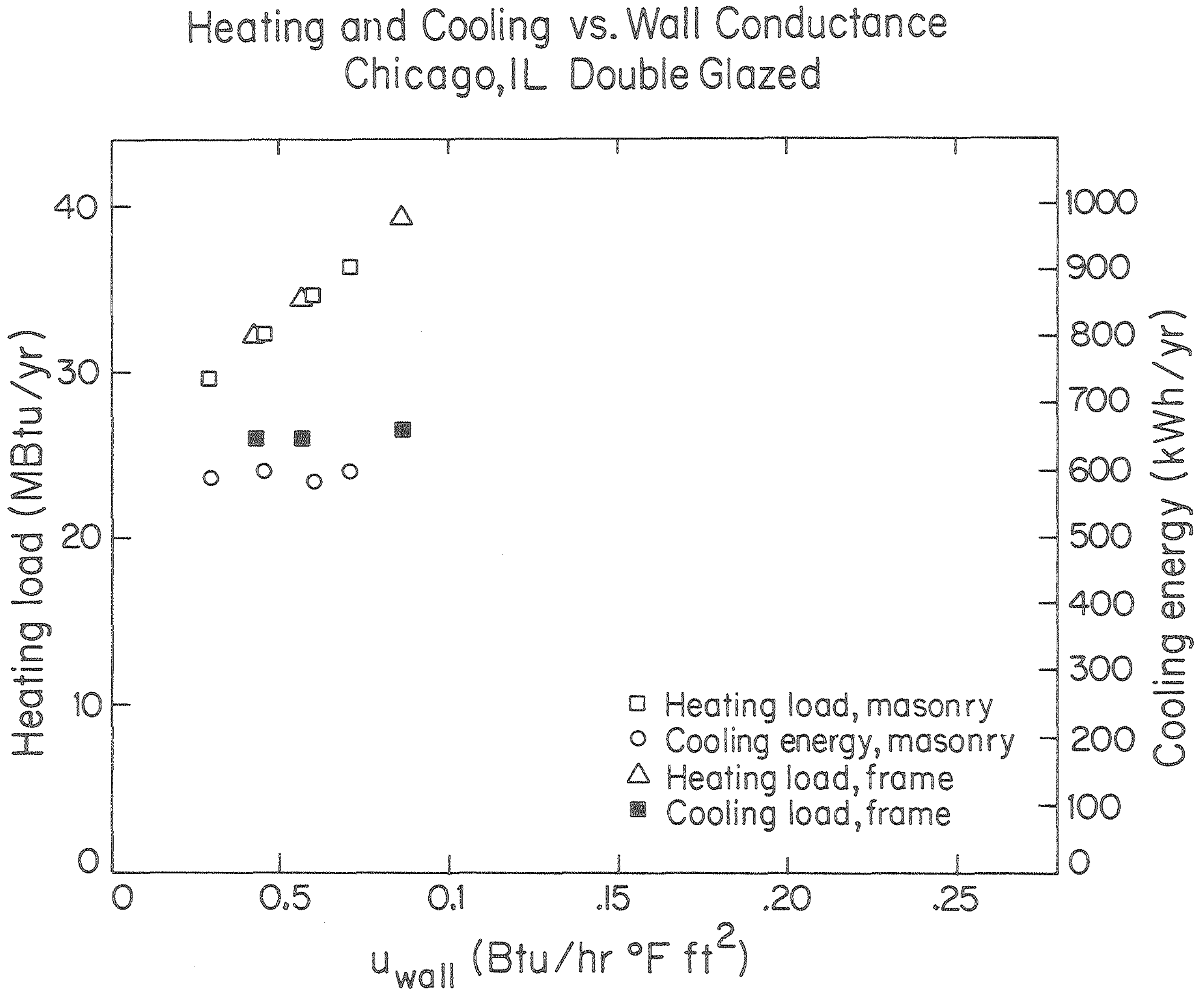

Figure 5

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FOOTNOTES:

1. U. S. Department of Energy, Office of Consevation and Solar Energy, Office of Buildings and Community Systems, "Notice of Proposed Rulemaking, Energy Performance Standards for New Buildings." DOE/CS/0112, November, 1979.

2. M. Lokmanhekim, et. al. "DOE-2, A New State-of-the-Art Computer Program for the Energy Utilization Analysis of Buildings." Lawrence Berkeley Laboratory, LBL-8974, 1979. Presented to the Second International CIB Symposium on Energy Conservation in Built Environment, Copenhagen, Denmark, May 28 - June 1, 1979.

3. ASHRAE "Handbood of Fundamentals", American Society of Heating, Refrigeration, and Air Conditioning Engineers, New York City, 1977, Chapter 22.

4. "Economic Analysis of Proposed Building Energy Performance Standards" Pacific Northwest Laboratory, PNL-3044, 1979.

5. D.B. Goldstein, M.D. Levine, J. Mass, "Methodology and Assumptions for the Evaluation of Building Energy Performance Standards", Lawrence Berkeley Laboratory, LBL-9110, 1980.

6. Steven R. Petersen, "Economic Analysis of Insulation in Selected Masonry and Wood-Frame Walls", Center for Building Technology, National Bureau of Standards, NBSIR 79-1789.

7. Letter of July 23, 1979 from Bill Kolar at the American Institute of Architects Research Corporation (AIA/RC), Washington, D.C. to Mark Levine, Lawrence Berkeley Laboratory, summarizing National Association of Home Builders/Research Foundation (NAHB/RF) date on masonry insulation costs.

8. The AIA/RC data (ref. 7) for furring cost are ambiguous as to whether the insulation is included in the price for furring. We assume it is included based on discussions with Bill Kolar of AIA/RC. Also, the cost of furring in this masonry data base is so low (11¢ ft^2 for furring 1" x 3" strips); and the furring costs given by NAHB (see Ref. 14) are also comparably low, even for 3" furring, that it is unreasonable to expect that the 32¢/ft^2 cost for 2" x 3" furring does not also include the insulation (insulation batts alone cost 19¢/ft^2).

9. A.J. Gadgil "TWOZONE User's Manual", Lawrence Berkeley Laboratory, LBL-6840, 1978.

10. A.J. Gadgil, D.B. Goldstein, J. Mass, "A Heating and Cooling Loads Comparison of Three Building Simulation Models for Residences" New York: R. Fazzolare and C. Smith. Changing Energy Futures (New York: in Pergamon Press, 1979).

11. B.A. Peavy, et. al., "Dynamic Thermal Performance of an Experimental Masonry Building", Center for Building Technology, National Bureau of Standards, NBS Building Science Series 45, 1975.

12. Robert C. Sonderegger, "Dynamic Models of House Heating Based on Equivalent Thermal Parameters", Princeton University, Center for Environmental Studies, 1977.

13. D.B. Goldstein, "Some Analytic Models of Passive Solar Building Performance", Lawrence Berkeley Laboratory, LBL-7811, 1978.

14. "Selected Cost Data on Residential Construction", NAHB/RF, Rockville, Md., 1977.

Figure Captions:

1) Heating load and cooling energy as a function of wall conductance (U value), for different types of masonry and frame wall section in Ft. Worth, Texas.

2) Heating load and cooling energy as a function of wall conductance (U value), for different types of masonry and frame wall section in Atlanta, Georgia.

3) Heating load and cooling energy as a function of wall conductance (U value), for different types of masonry and frame wall section in Phoenix, Arizona. Points marked "incomplete cooling energy" represent hours in which the air conditioner is too small to keep up with the loads. A properly sized air conditioner would use slightly more cooling energy.

4) Heating load and cooling energy as a function of wall conductance (U value), for different types of masonry and frame wall section in Chicago, Illinois.

5) Heating load and cooling energy as a function of wall conductance (U value), for different types of masonry and frame wall section in Chicago, Illinois for a double glazed house. The optimum house in Chicago has triple glazing.