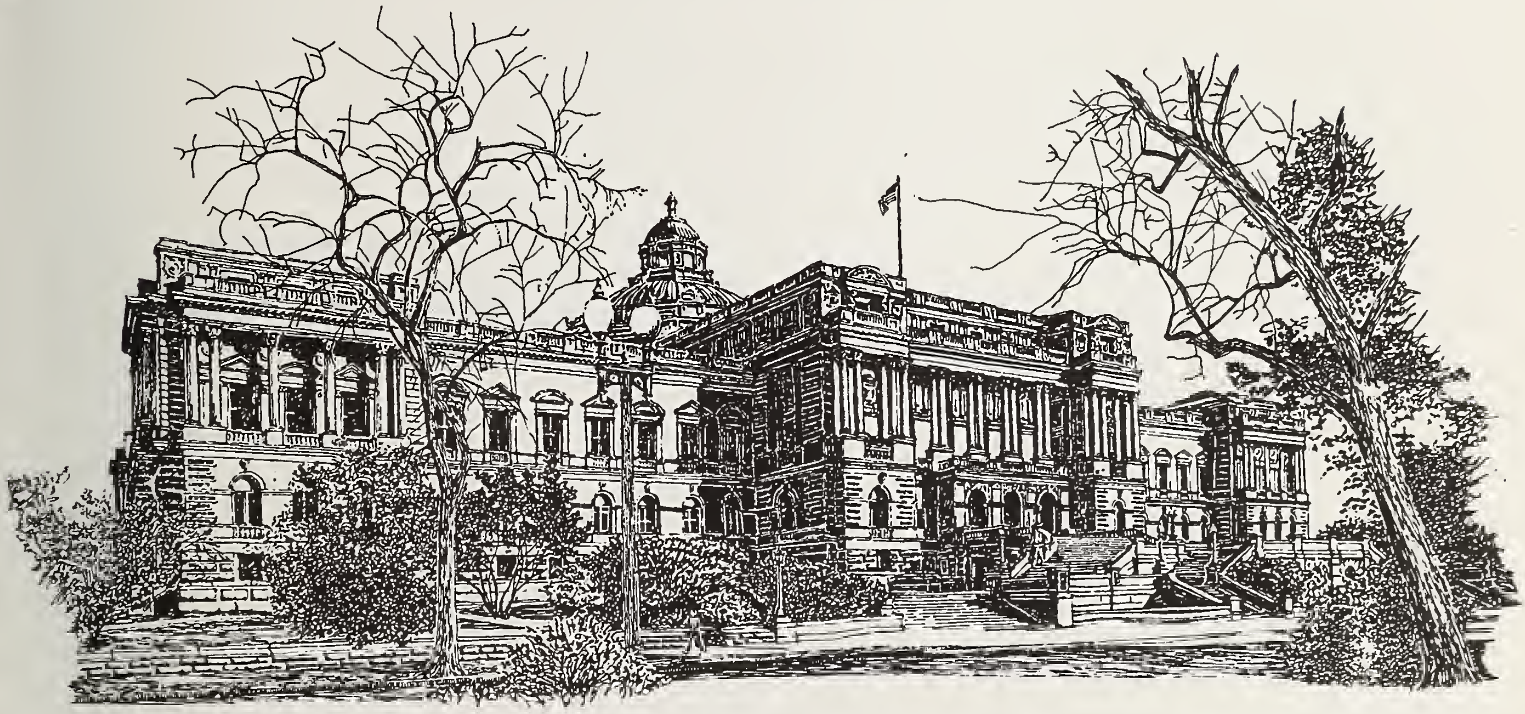
NBSIR 81-2317

Energy Conservation By Multiple Glazing on Heavy Masonry Buildings



U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Center for Building Technology
Washington, DC 20234

June 1981

Prepared for:
Office of the Architect of the Capitol
Washington, DC 20515

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ENERGY CONSERVATION BY MULTIPLE GLAZING ON HEAVY MASONRY BUILDINGS

E. Thomas Pierce

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

The BLAST-2 computer program is used to investigate multiple glazing as a means to reduce the energy consumption of two buildings of the Library of Congress in Washington, D.C. The Thomas Jefferson Building is of very heavy masonry construction, and the John Adams Building is of heavy masonry. The techniques of modeling the building load and air system performance are explained. The results are presented and discussed. Typical perimeter modules of various floors simulated with single, double, and triple glazing are faced in four compass directions. Similar results are obtained over a range of models. Application of double glazing will save up to ten percent of heating energy, but not much cooling energy, while maintaining present operating requirements.

Keywords: BLAST (computer program); building energy analysis; energy conservation for non-residential buildings; historic preservation and energy conservation; load calculation; masonry thermal mass; multiple glazing; system simulation.

PREFACE

This report was prepared at the request of the Architect of the Capitol to the Building Thermal Performance Division, Center for Building Technology, NBS. Support of the study was a cooperative effort by NBS and the Architect of the Capitol. The patience and encouragement of Mr. J. Raymond Carroll, P.E., Director of Engineering for the Architect, are much appreciated. The staff of the Architect assisted in determining the significant architectural and HVAC parameters of the buildings studied. Particularly helpful were Scott Birkhead, Douglas Knowles, Gary Lukas, and Philip Riley.

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CONVERSION FACTORS TO METRIC (SI) UNITS

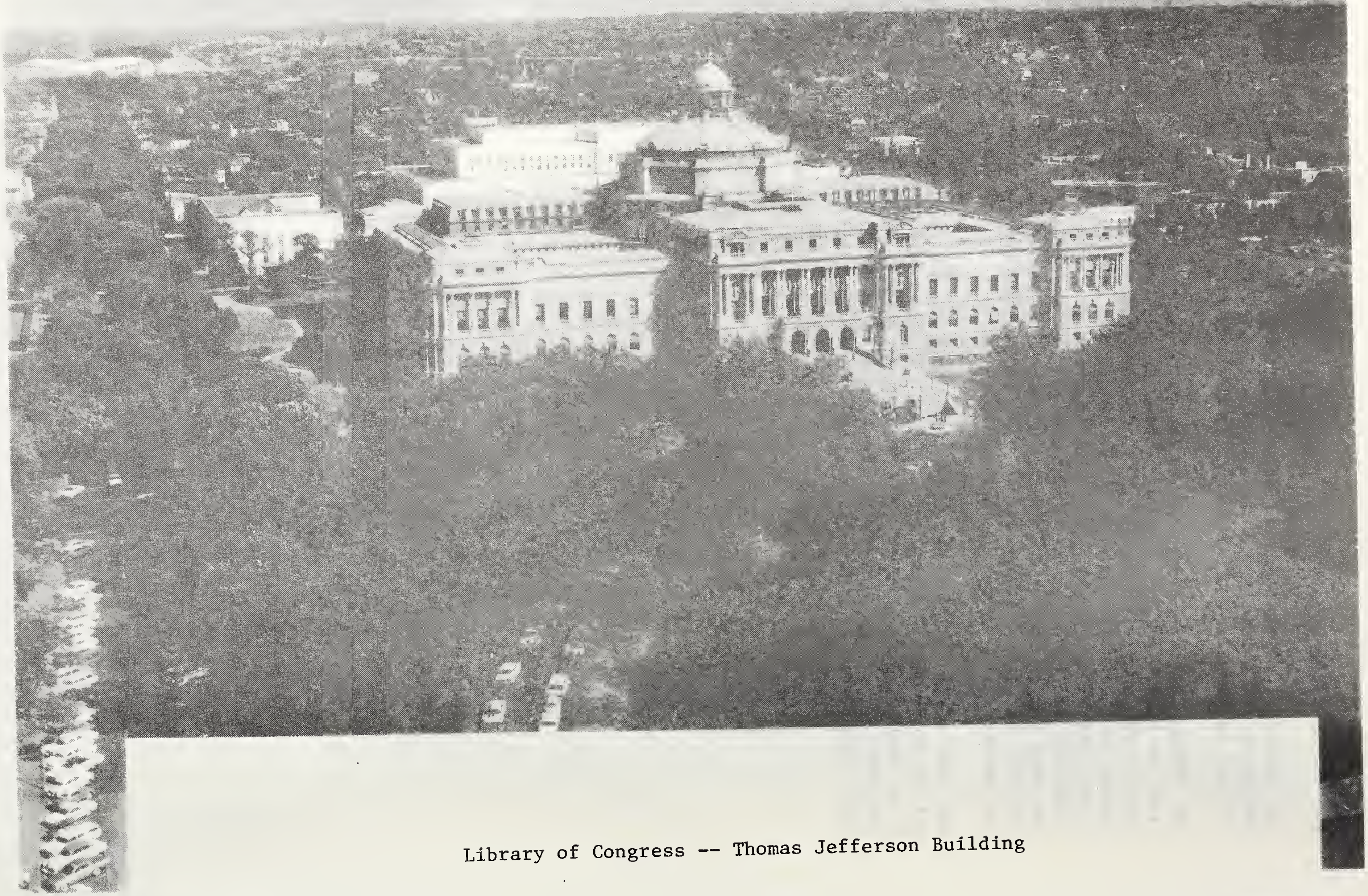
Physical Quantity	Symbol	To Convert From	To	Multiply By
Length	ℓ	ft	m	3.05×10^{-1}
Area	A	ft^2	m^2	9.29×10^{-2}
Volume	$\forall$	ft^3	m^3	2.83×10^{-2}
Temperature	T	Fahrenheit	Celsius	$t_C = (t_F - 32)/1.8$
Temp. Diff.	ΔT	Fahrenheit	Kelvin	$K = (\Delta T_F)/1.8$
Mass		lb	kg	4.54×10^{-1}
Density	ρ	lb/ft^3	kg/m^3	1.602×10^{1}
Thermal Conductivity	k	$Btu \cdot in/h \cdot ft^2 \cdot °F$	$W/m \cdot K$	1.442×10^{-1}
Thermal Transmittance (or Conductance)	U	$Btu/h \cdot ft^2 \cdot °F$	$W/m^2 \cdot K$	5.68
Thermal Resistance	R	$h \cdot ft^2 \cdot °F/Btu$	$m^2 \cdot K/W$	0.176
Heat Flux Rate	q/A	$Btu/h \cdot ft^2$	W/m^2	3.15
Heat Flow	q	Btu/h	W	2.93×10^{-1}
Volumetric Flow Rate	v	ft^3/min	m^3/s	4.72×10^{-4}
Velocity	V	ft/min	m/s	5.08×10^{-3}
Specific Heat	C_p	$Btu/lb \cdot °F$	$J/kg \cdot K$	4.19×10^{3}
Permeance		perm	$kg/Pa \cdot s \cdot m^2$	5.72×10^{-11}

1. INTRODUCTION

The Architect of the Capitol has requested an evaluation of the effects on energy of the installation of multiple glazing for two buildings of the Library of Congress. This report is the result.

The Thomas Jefferson Building is the large ornate structure directly east from the U.S. Capitol. Formerly known as the Main Library of Congress Building, it was completed about 1897. Construction is of heavy brick with stone facing on the exterior. The lower floors are supported by barrel-arched brick, while the second floor (the lightest floor here considered in this building) is supported by terra cotta arches supported on iron joist beams. The dead weight of the floors is estimated to range from 780 kg/m^2 (160 lbm/ft^2) for the second floor to 2300 kg/m^2 (480 lbm/ft^2) for the basement. The masonry walls range up to over 1.6 m (over 5 ft) in thickness.

The John Adams Building has also been known as the Annex (and was also formerly called the Thomas Jefferson Building). It was completed in the 1930's, and is of rather heavy masonry also, though not nearly as heavy as the Thomas Jefferson Building. The lower floors are of 8-inch concrete, and the masonry walls range down to about 0.3 m (about 1 ft) in thickness.



Library of Congress -- Thomas Jefferson Building

Library of Congress -- John Adams Building

2. THE BLAST-2 IMPLEMENTATION

2.1 BLAST-2 MODEL DEVELOPMENT

The effectiveness of storm windows for energy conservation would depend on orientation, space geometry, thermal mass, and Heating, Ventilating, Air Conditioning (HVAC) design. For the present work it was necessary to abstract from the rather complex real buildings in order to develop a set of simplified models which would adequately cover the range of applicable parameters. The models developed employ typical perimeter spaces, as shown in figure 1. The spaces or modules are the depth of the perimeter areas, usually from the exterior wall to the stack wall; the height is the floor-to-floor height, and the width is that of the typical bay or module for the building considered. Internal furnishings and live load are simulated as partitions at the sides of the module, adjusted so as have correct radiation exchange with the exterior wall. As in the real buildings, from two to four of these modules are stacked one above the other. Ten such stacks of modules are served by a model of the appropriate HVAC system. The modules are based on the dimensions and heat flow of the real building, and are intended to cover a range from the moderately heavy construction of the John Adams fifth floor study rooms to the very heavy construction of the Thomas Jefferson. Each of four models is studied with rotation to face in each of four compass directions. Triple as well as double glazing is compared with the present single glazing, so as to obtain a greater range of energy effectiveness values.

The four series of computer runs were as follows:

1) Series 300, the two floors of the John Adams Building fifth-floor study rooms.

2) Series 200, the ground through third floors of the John Adams Buiding. (There are no windows on the fourth floor.)

3) Series 500, the basement through second floors of the Thomas Jefferson Building, testing treatment of the courtyard windows.

4) Series 400, the same floors of the Thomas Jefferson Building, backed up against the book stacks, testing treatment of the exterior windows.

2.2 DETAILED DESCRIPTIONS OF THE MODELS

As mentioned above, single, double, and triple glazings were compared, and venetian blinds were used on the John Adams Building. The BLAST-2 implementation of these window treatments is as shown in table 1.

An attic was used above series 300, 400, and 500, as shown in figure 2. Since the purpose of the attic is only to achieve a file of floor surface temperatures for use in the zone below, an exact model is not required. The attic constructions were based on those of the John Adams Building, with 0.5 air changes per hour to simulate infiltration. Note that the room below an

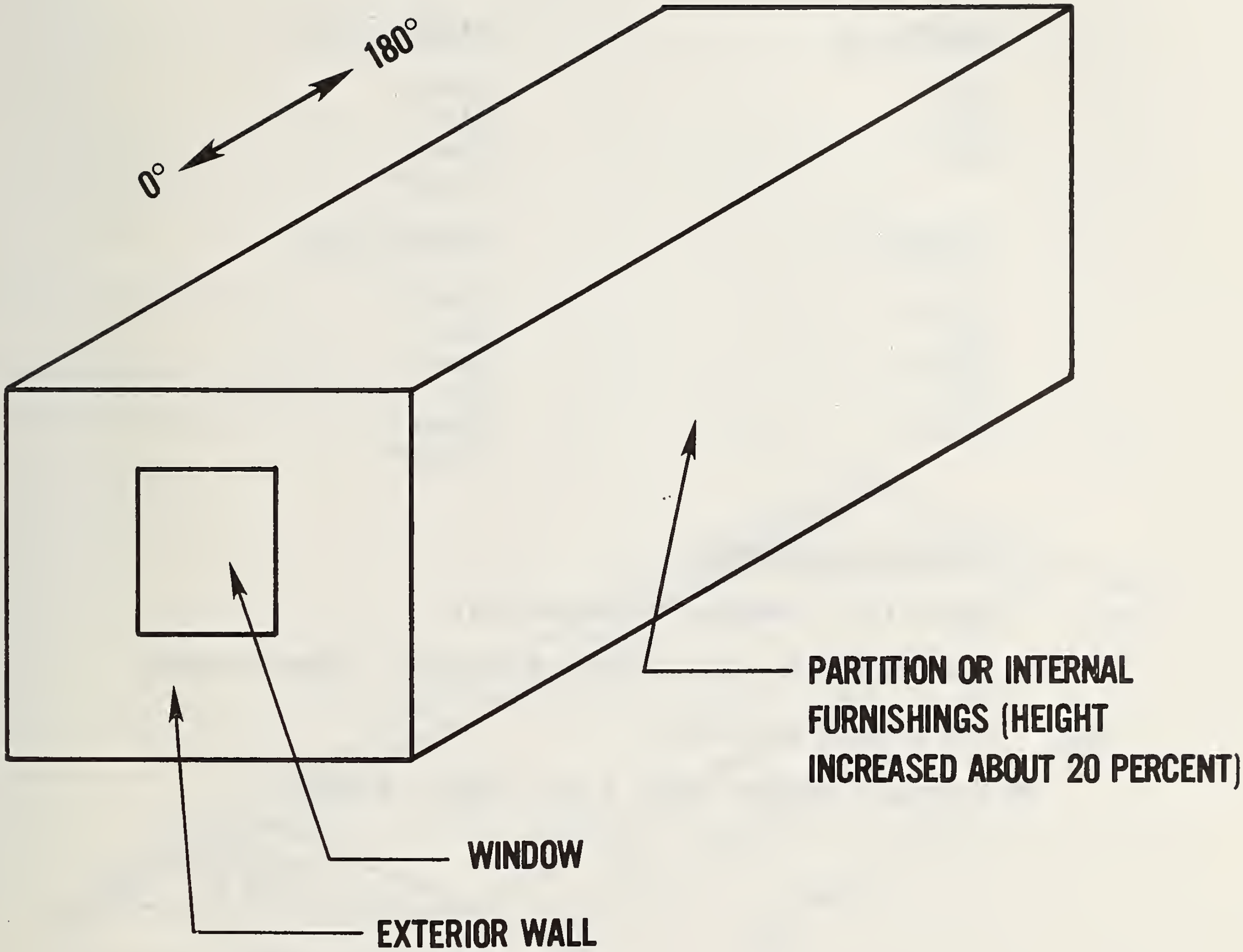


Figure 1. Typical space

Table 1. Windows - Layers and Materials

Window - 1	Windows - 11
Glass	Glass V-Blind

Window - 2	Window - 12
Glass Air Glass	Glass Air Glass V-Blind

Window - 3	Window - 13
Glass Air Glass Air Glass	Glass Air Glass Air Glass V-Blind

BLAST-2 Input Text

```
UNITS (IN = ENGLISH, OUT = ENGLISH),

GLASS = (GLASS, VERY SMOOTH, R = 0.0236, TRANS = 0.870),

AIR = (AIR, R = 0.91),

V-BLIND = (SHADE, REF = 0.250, TRANS = 0.650).
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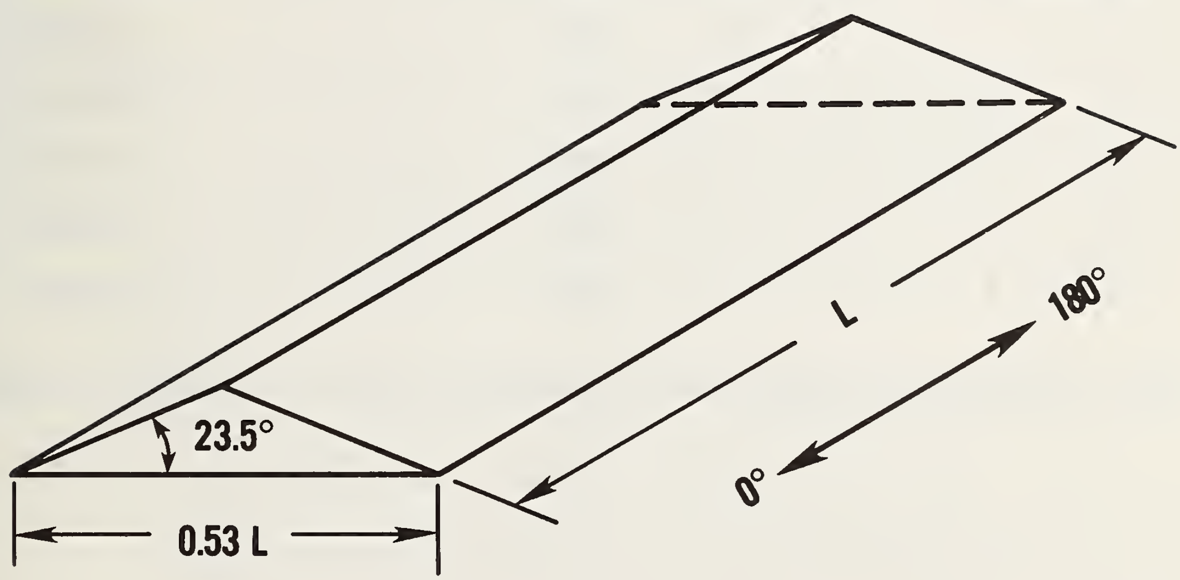

Figure 2. Construction of attic. An attic is used to achieve a file of floor surface temperatures for use in the zone below.

attic need not have the same construction for its ceiling as that used for the attic floor.

Table 2 shows the application of the various weight constructions to the different series of computer runs, where "weight" means the mass per square foot of the wall or floor area of the construction except in the case of the last two entries. For MIDBRICK and MAXBRICK, "weight" is the effective or equivalent thermal storage of the construction for use as an interior surface. Symbol "E" indicates the construction used in the models of the exterior walls.

A range of weights is represented, with series 300 having the lightest constructions. The brick is used as a convenient unit for much of the masonry. Thus, BRICK-3 represents 12 inches of masonry with a density of 120 lbm/ft^3. Concrete-4 and -8, however, indicate thickness in inches.

Table 3 shows these applications of the constructions in greater detail, and table 4 provides appropriate descriptive parameters as input to BLAST-2.

Detailed understanding of other features of the BLAST-2 models may be best gained from the text of the BLAST-2 input codes, which are available to those interested.

Table 2. Constructions/Applications

Item	Weight (lbm/ft^2)	Applications (Series) 300	200	500	400
Attic	--	X		X	X
Venetian Blinds	--	X	X		
Gallery Ceiling	0			X	X
Annex Study Wall	10	X			
Brick-1 Furnishings	40		X	X	X
Concrete-4	45	X			
Annex Stack Wall	65		X		
Concrete-8	95	X	X	X	X
Brick-3	120	E			
Brick-4	160		E	X	X
Brick-7	280			E	E
Midbrick	320			X	X
Maxbrick	480			X	X

Symbol E indicates the construction used in the models of the exterior walls.

Table 3. Constructions/Areas

Constructions, Series 300, John Adams Building

	Area (ft^2)	Construction
Lower Fifth Floor		
	51.4	Brick-3 Exterior Wall
	16.6	Test Window
	256.6	Annex Study Walls
	88.8	Concrete-8 Floor
	88.8	Concrete-4 Ceiling
Upper Fifth Floor		
	46.4	Brick-3 Exterior Wall
	16.6	Test Window
	251.6	Annex Study Walls
	88.8	Concrete-4 Floor
	88.8	Concrete-4 Ceiling to Attic

Constructions, Series 200, John Adams Building

	Area (ft^2)	Construction
Ground Floor		
	174.1	Brick-4 Exterior Wall
	35.9	Test Window
	210.0	Annex Stack Wall
	469.0	Concrete-8 Floor
	469.0	Concrete-8 Ceiling
	1206.0	Brick-1 Furnishings
First Floor		
	170.1	Brick-4 Exterior Wall
	39.9	Test Window
	210.0	Annex Stack Wall
	469.0	Concrete-8 Floor
	469.0	Concrete-8 Ceiling
	1206.0	Brick- Furnishings
Second Floor		
	172.0	Brick-4 Exterior Wall
	38.0	Test Window
	210.0	Annex Stack Wall
	469.0	Concrete-8 Floor
	469.0	Concrete-8 Ceiling
	1206.0	Brick-1 Furnishings

Table 3. Constructions/Areas (Continued)

Constructions, Series 200 (Continued)

	Area (ft^2)	Construction
Third Floor		
	200.0	Brick-4 Exterior Wall
	38.0	Test Window
	238.0	Annex Stack Wall
	469.0	Concrete-8 Floor
	469.0	Concrete-8 Ceiling
	1206.0	Brick-1 Furnishings

Constructions, Series 500, Thomas Jefferson Building

	Area (ft^2)	Construction
Basement		
	176.7	Brick-7 Courtyard Wall
	23.4	Test Window
	176.7	Brick-7 Exterior Wall
	23.4	Double-Glazed Window
	507.5	Maxbrick Floor
	507.5	Midbrick Ceiling
	1162.0	Brick-1 Furnishings
First Floor		
	254.5	Brick-7 Courtyard Wall
	50.0	Test Window
	254.5	Brick-7 Exterior Wall
	50.0	Double-Glazed Window
	507.5	Midbrick Floor
	507.5	Brick-7 Ceiling
	1764.0	Brick-1 Furnishings
Second Floor		
	387.0	Brick-7 Courtyard Wall
	48.0	Test Window
	387.0	Brick-7 Exterior Wall
	48.0	Double-Glazed Window
	507.5	Brick-7 Floor
	507.5	Gallery Ceiling to Attic
	2520.0	Brick-1 Furnishings

Table 3. Constructions/Areas (Continued)

Constructions, Series 400, Thomas Jefferson Building

	Area (ft^2)	Construction
Basement		
	176.7	Brick-7 Exterior Wall
	23.4	Test Window
	200.1	Brick-7 Stack Wall
	507.5	Maxbrick Floor
	507.5	Midbrick Ceiling
	1162.0	Brick-1 Furnishings
First Floor		
	254.5	Brick-7 Exterior Wall
	50.0	Test Window
	304.5	Brick-7 Stack Wall
	507.5	Midbrick Floor
	507.5	Brick-4 Ceiling
	1764.0	Brick-1 Furnishings
Second Floor		
	387.0	Brick-7 Exterior Wall
	48.0	Test Window
	435.0	Brick-7 Stack Wall
	507.5	Brick-4 Floor
	507.5	Gallery Ceiling to Attic
	2520.0	Brick-1 Furnishings

Constructions, Attic

	Area (% re floor)	Construction
Attic for Series 400, 500		
	109.0	Roof
	11.5	Brick-1 Gables
	100.0	Concrete-8 Floor
Attic for Series 300		
	109.0	Roof
	11.5	Brick-1 Gables
	100.0	Concrete-4 Floor

Table 4. Constructions/Details

BLAST-2 Symbols	L	K	CP	D
Units	(ft)	$(\frac{Btu}{h \cdot ft \cdot °F})$	$(\frac{Btu}{lbm \cdot °F})$	$(\frac{lbm}{ft^3})$
<u>Annex Study Wall</u>, Series 300				
Cork	.0417	.024	.38	22
Sheet Metal	.0052	26.200	.12	489
Cork	.1458	.024	.38	22
Sheet Metal	.0052	26.200	.12	489
Cork	.0417	.024	.38	22
<u>Annex Stack Wall</u>, Series 300				
Plaster	.0833	.417	.20	116
Clay Tile	.3333	.330	.20	70
Airspace (R = 0.91)	---	---	---	---
Clay Tile	.3333	.330	.20	70
Plaster	.0833	.417	.20	116
<u>Roof</u>, Attic				
Sheet Copper	.0052	227.000	.09	556
Nailing Concrete	.2083	.096	.20	40
Concrete	.2500	1.000	.20	140
Cork	.1458	.024	.38	22
<u>Single-Layer Constructions</u>				
Gallery Ceiling (R = 0.07)	---	---	---	---
Brick-1	.3330	.420	.20	120
Concrete-4	.3330	1.000	.20	140
Concrete-8	.6667	1.000	.20	140
Brick-3	1.0000	.420	.20	120
Brick-4	1.3330	.420	.20	120
Brick-7	2.3330	.420	.20	120
Midbrick	1.3330	.420	.40	120
Maxbrick	1.3330	.420	.60	120

3. SPECIAL CONSIDERATIONS

3.1 MASONRY WALLS AND THERMAL MASS

The modeling of masonry walls requires thickness for both thermal resistivity and thermal storage. The algorithms within BLAST-2 are able to calculate the performance of only about two feet of masonry, but the thermal storage may be augmented by increasing either the density or specific heat of the simulated masonry used in the model. Selecting masonry for the model is further complicated by voids and sources of heat gain or loss within the wall, and by the curved paths for heat flow around windows.

BLAST-2 employs a one dimensional model for exterior envelope components such as walls and windows. This parallel heat-flow model does not provide for the curving paths of heat flow through the masonry around the windows. The path length or effective thickness is different from the real wall thickness.

Voids or chases within the wall carry supply air, as well as steam, hot water, and chilled water for supply to induction unit booster or reheat coils. These voids thus represent further deviations from a parallel heatflow model, as well as sources of heat gain or loss within the masonry.

Each of these considerations was a factor in developing the detailed constructions for the models, as described below.

3.2 AIR HANDLING UNITS

The simulted HVAC system for each of the four modeling series was based on the BLAST-2 implementation of the systems in the real building. Thus real primary air quantities and temperatures were simulated, with appropriate modifications for BLAST-2 limitations such as lack of booster cooling coils, so as to achieve the proper energy results. Figure 3 shows the BLAST-2 control strategy used. The cold deck temperature is manually reset so as to maintain a space temperature between 70 and 72°F, as required by the books, and large heating and cooling capacities assure that the space temperature is held in that range.

The proper outside air quantity is established by the BLAST-2 exhaust air volume; supply fan pressure is reduced and cold deck temperature is raised where supply air volumes must be increased over those of the real systems.

3.3 SOLAR ENERGY THROUGH WINDOWS

Since the subject of this study is energy and storm windows, we also asked if the reduction of solar energy associated with venetian blinds might be a problem. Annual runs were performed for a south-facing window with single, double, and triple glazing, using the Typical Meteorological Year (TMY) weather file. Two cases were compared: 1) no blinds, and 2) closed light-weight venetian blinds (light-colored).

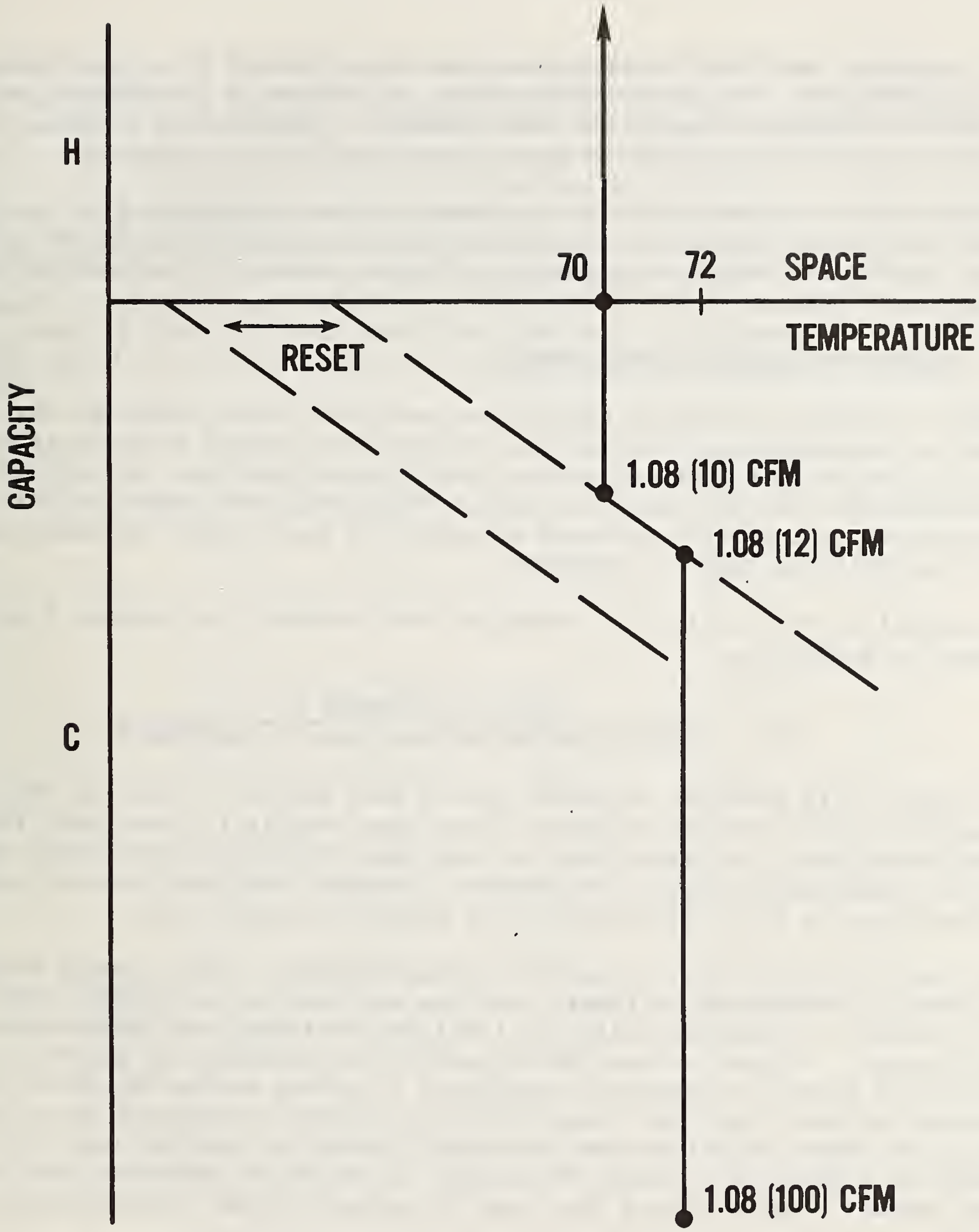

Figure 3. BLAST-2 control strategy

Cold deck is manually reset to maintain space temperature. The control strategy establishes the control profile for the loads calculation. Between the control temperatures, the capacity is 1.08 (ΔT) CFM, (UNITS = ENGLISH).

The conclusion was that the percentage savings of energy by storm windows are not significantly affected by the presence or absence of the blinds, as long as there is uniformity among the runs compared. There is, of course, more heating and less cooling energy needed when the blinds are closed.

We chose to have venetian blinds on the John Adams Building and not on the Thomas Jefferson Building, as consistent with their projected future occupancies. The Thomas Jefferson Building is in the process of restoration for use, in part, as a museum.

3.4 RADIATION EXCHANGE WITHIN SPACES

BLAST-2 calculates an energy balance for each hour, which includes the radiation exchange among the various boundary surfaces of an analysis zone. Owing to the massive constructions of the library buildings, as well as to the substantial thermal mass of interior furnishings and books, it was desired that most of the exchanged radiation be kept within the space and away from building exterior surfaces.

The simplified view factor for radiation from surface 1 to surface 2 is defined in BLAST-2 as

$$F_{12} = \frac{\text{(area of surface 2)}}{\text{(total area of surfaces seen by surface 1)}}$$

For a cube, this equation is exact, with a view factor F = 0.2 for the radiation between any two surfaces of the cube, and it is less exact for other geometries. To assure that no more than 20 percent of interior radiation is calculated to fall on an exterior surface, the total area of interior surfaces must be five times that of the exterior surface area.

The solar radiation that is received through windows in some energy analysis programs is distributed uniformly over the surfaces of an analysis zone. This creates a problem when lightly insulated buildings are modeled as a single space. In such a case, where most of the surfaces are exterior, a substantial portion of the solar radiation is placed on the inside of the exterior surfaces, and then leaves the space during the current hour, without having the proper effect on the calculated heating or cooling load. The "fix" adopted in BLAST-2 is to throw 80 percent of the solar radiation onto the floor surface, and to spread the other 20 percent on the other surfaces.

A third element of the radiation exchange in BLAST-2 is found in what happens when energy falls on an interior surface. As with an exterior surface, the surface flux and heat transfer are determined by the conduction transfer functions (CTF) and by the other-side surface temperature. This other-side temperature is the current-hour inner-side surface temperature. Thus, when 80 percent of the solar radiation falls on the floor, the floor may have an excessively raised temperature, but incorrect heat transfer through the floor should not be a difficulty. The thing to watch out for is excessive radiation exchange with the exterior envelope of the building, as affected by the view factors.

The above aspects of the energy balance and radiation exchange were considered important in developing the BLAST-2 models, and were implemented in our analysis as follows: 1) the BLAST-2 source code was modified and recompiled to reduce the floor-surface fraction of solar radiation from 80 percent to 50 percent; 2) interior furnishings were modeled as extra interior surfaces, to provide additional thermal mass for heat storage, and to assure that the radiation to exterior surfaces was not excessive; and 3) program-calculated view factors were compared with what they should have been, again to assure reasonable quantities of radiation exchange. In terms of the model shown above in figure 1, this means that the side partitions of the module are made about 20 percent greater in height than the real floor-to-floor height.

4. RESULTS AND CONCLUSIONS

Table 5 shows the heating and cooling results. Although there is some variation, the results are relatively uniform over the four compass directions. The effects on cooling energy of the storm windows are small, as is to be expected. Table 6 summarizes the heating data for single and double glazing and gives two measures of the effectiveness of double glazing: the percent of heating energy saved, and the savings per square foot of window.

The purchase of storm windows probably cannot be justified solely on the basis of the cost of the energy alone. For example, if we use simple payback analysis of the heating energy savings for the 200 series, with distillate fuel at $7.05 per 10^6 Btu [1], and with storm windows at $5.93 per square foot [2], the payback period is thirteen years. However, with 40 percent indoor relative humidity, storm windows would greatly reduce the condensation of water during cold periods.

Table 5A. Cooling Data (Btu x 10^6/yr)

	Single Glazed	Double Glazed	Triple Glazed	Double Saves	Triple Saves
	Series 300				
S	234.8	233.7	233.0	1.1	1.8
W	235.4	234.3	233.6	1.1	1.8
E	237.0	236.0	235.2	1.0	1.8
N	232.6	231.6	231.1	1.0	1.5
	Series 200				
S	725.9	717.3	711.0	8.6	14.9
W	742.5	733.2	725.4	9.3	17.1
E	760.1	749.6	740.3	10.5	19.8
N	691.1	685.7	681.4	5.4	9.7
	Series 500				
S	853.3	856.0	851.7	-2.7	1.5
W	942.1	945.0	939.2	-2.9	2.9
E	939.3	940.7	933.9	-1.4	5.4
N	873.3	878.6	875.5	-5.3	-2.2
	Series 400				
S	819.0	824.3	820.0	-5.3	-1.0
W	824.7	827.1	821.5	-2.4	3.2
E	843.4	844.9	838.0	-1.5	5.4
N	770.2	776.2	774.1	-6.0	-3.9

Table 5B. Heating Data (Btu x 10^6/yr)

	Single Glazed	Double Glazed	Triple Glazed	Double Saves	Triple Saves
	Series 300				
S	512.5	495.8	491.3	16.7	21.2
W	524.6	507.3	502.4	17.3	22.2
E	521.5	504.2	499.4	17.3	22.1
N	537.9	520.4	515.0	17.5	22.9
	Series 200				
S	917.9	823.4	796.1	94.5	121.8
W	991.3	890.6	858.9	100.7	132.4
E	983.4	883.1	851.3	100.3	132.1
N	1033.4	930.7	898.0	102.7	135.4
	Series 500				
S	874.0	817.7	799.9	56.3	74.1
W	903.5	845.8	825.8	57.7	77.7
E	903.2	845.1	825.0	58.1	78.2
N	867.6	810.5	791.2	57.1	76.4
	Series 400				
S	699.7	650.9	636.6	48.8	63.1
W	735.2	679.5	661.8	55.7	73.4
E	734.8	679.4	661.4	55.4	73.4
N	743.9	687.1	669.0	56.8	74.9

Table 6. Savings of Heating Energy

	Series 300	Series 200	Series 500	Series 400
Single Glazed, Btu x 10^6	2096.5	3926.0	3548.3	2913.6
Double Glazed, Btu x 10^6	2027.7	3527.8	3319.1	2696.9
Savings, Btu x 10^6	68.8	398.2	229.2	216.7
Savings, Btu x $10^6/ft^2$ of Windows	.0519	.0656	.0472	.0446
Savings, Percent	3.28	10.14	6.46	7.44

5. REFERENCES

1. Federal Register, Federal Energy Management and Planning Programs; Methodology and Procedures for Life Cycle Cost Analysis (Average Fuel Costs), Vol. 45, No. 209, October 27, 1980.

2. Knowles, Douglas, Personal communication of quotation he had received for acrylic inside storm window panels. Date of quotation was April 29, 1980.

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Office of the Architect of the Capitol
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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here*)

The BLAST-2 computer program is used to investigate multiple glazing as a means to reduce the energy consumption of two buildings of the Library of Congress in Washington, D.C. The Thomas Jefferson building is of very heavy masonry construction, and the John Adams building is of heavy masonry. The techniques of modeling the building load and air system performance are explained. The results are presented and discussed. Typical perimeter modules of various floors simulated with single, double, and triple glazing are faced in four compass directions. Similar results are obtained over a range of models. Application of double glazing will save up to ten percent of heating energy but not much cooling energy while maintaining present operating requirements.

12. KEY WORDS (*Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons*)

building energy analysis; energy conservation for non-residential buildings; historic preservation and energy conservation; load calculation; masonry thermal mass; system simulation

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