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MIXED STRATEGIES FOR ENERGY CONSERVATION AND ALTERNATIVE ENERGY UTILIZATION (SOLAR) IN BUILDINGS

Final Report, Volume III—Appendixes

November 1977
(TIC Issuance Date)

Work Performed Under Contract No. EY-76-C-03-1234

Energy Resources Center
Honeywell, Incorporated
Minneapolis, Minnesota

U. S. DEPARTMENT OF ENERGY

Division of Buildings and Community Systems

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FINAL REPORT

VOLUME III - APPENDIXES

Date Published-June 1977

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PREPARED FOR THE
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Office of the Assistant Administrator for Conservation
Division of Buildings and Conservation Services

ENERGY RESOURCES CENTER
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LIST OF APPENDICES FOR VOLUME III, 41025

APPENDIX A
BUILDING CHARACTERISTICS

INTRODUCTION

This appendix summarizes building characteristics used to determine heating and cooling loads for each of the five building types in each of the four regions. For the selected five buildings, the following data is attached:

- New and existing construction characteristics
- New and existing construction thermal resistance
- Floor plan and elevation
- People load schedule
- Lighting load schedule
- Appliance load schedule
- Ventilation schedule
- Hot water use schedule

The building sizes were selected from looking over previous studies. Table A-1 places the various studies in a matrix for quick comparison.

The interval loads have a set schedule but might have a different peak in various situations. Therefore, the basic schedule is presented in terms of percent of maximum. The maximum internal loads are summarized in Table A-2.

Table A-1. Building Size (Ft^2) Summary

BUILDING TYPE	REPORTS							HONEYWELL SELECTION	
	90-75	G.E.	TRW	Westing-house	Norman Associates	NAHB New	NAHB Existing	New	Existing
Single Family	1,660 (1)*	1,800+B (2)	1,400 (1)	1,550 (1)		1,570 (1)	1,213 (1)	1,512 28x54	1,204 28x43 (1+B)
Apartment Building	18,000 (2)	21,600 (3)	3,200 (2)	14,600 (2.3)		14,400 (2.3)		14,400 98x49	14,400 98x49 (2+B)
Office Building	40,000= (3)	20,000 (2)	10,000 (2)	33,400 (3.34)	15,500			30,000 100x100	30,000 (3)
Store Building	32,400 (1)	5,200 (1)	15,000 (1)	1,400 (1)	4,915			5,000 40x125	5,000 40x125 (1)
School Building	40,000 (1)	52,000 (1)	9,600 (1)		18,927			39,750 265x150	39,750 (1) 265x150

* Numbers in parenthesis are the average number of floors in the building.

Table A-2. Maximum Internal Load Characteristics

Building Type	Occupancy[1]			Lighting[2] Watts/Ft^2		Appliances[3] BTU/hr
	Sensible BTU/hr	Latent BTU/hr	Peak Occupancy	Existing	New	
Single Family	250	200	4 people	1.0	1.0	5328 (New) 4352 (Existing)
Multi-Family	250	200	33 people (3.27/unit)	.75	.75	28,312
Retail Store	250	240	100 people (50 Ft^2/person)[4]	6.0	3.0	-
Office Building	250	200	300 people (100 Ft^2/person)[4]	3.0	2.0	-
School	210	140	265 people (150 Ft^2/person)[5]	3.0	2.0	3385

1 - TRW Phase O

2 - 1 + IES Lighting Handbook

3 - GE Phase O

4 - Westinghouse Phase O

5 - Minnesota State Dept. of Education

Thermal resistance values for still and moving air used in the study include:

- Still Air (Inner Surfaces)
  Horizontal Surface R = 0.061 ceiling
  R = 0.92 floor
  Vertical Surface R = 0.68 walls
- Moving Air (Outer Surfaces)
  Any Surface Orientation R = 0.2

SINGLE FAMILY RESIDENCE

The National Association of Home Builders Research Foundation, Inc. provided construction details for the new and existing homes. (See Appendix H). Size was held constant to limit the number of parameters changes necessary to analyze heating/cooling loads; especially those instances where levels of insulation were varied. The other data and schedules were obtained from local builders, and the Phase O reports. The data for single family residences includes the following:

- New and Existing Construction Characteristics
- New and Existing Construction Thermal Resistance
- Floor Plan and Elevation
- People Load Schedule
- Lighting Load Schedule
- Appliance Load Schedule
- Hot Water Use Schedule

Table A-3. New and Existing Single Family Residence Construction Characteristics

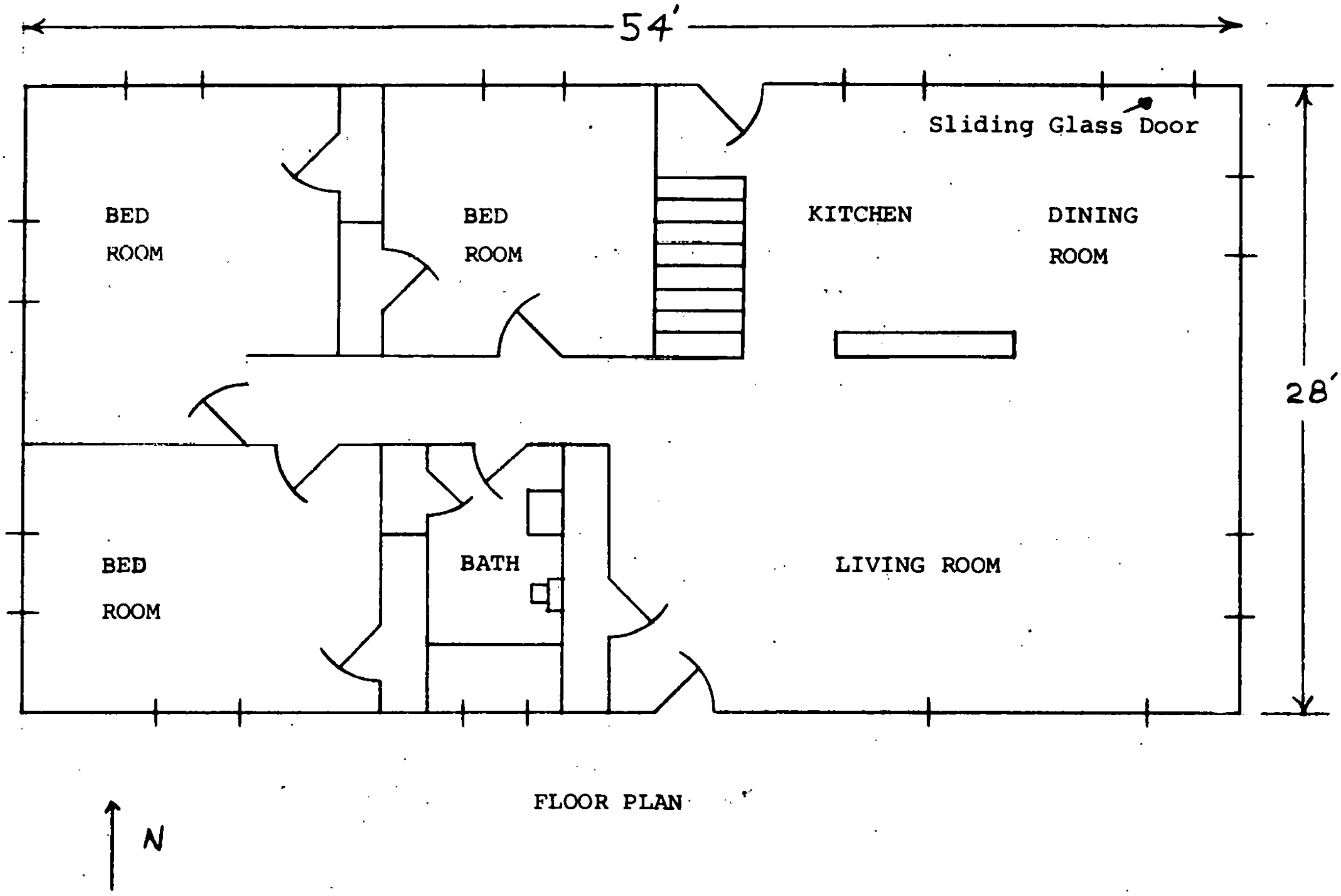
	EXISTING				NEW			
CHARACTERISTIC	NORTHEAST	NORTH CENTRAL	SOUTH	WEST	NORTHEAST	NORTH CENTRAL	SOUTH	WEST
Size - ft^2/fl	1204	1204	1204	1204	1512	1512	1512	1512
Dimensions	28'x43'	28'x43'	28'x43'	28'x43'	28'x54'	28'x54'	28'x54'	28'x54'
No. of Floors	2 (1+B)	2 (1+B)	1	1	2 (1+B)	2 (1+B)	1	1
Height of Story	8'	8'	8'	8'	8'	8'	8'	8'
Foundation Type	Basement	Basement	Crawl Space	Crawl Space	Basement	Basement	Slab	Slab
Roof Type	Gable	Gable	Gable	Gable	Gable	Gable	Gable	Gable
EXT. GLASS:								
Windows (ft^2)	174 w/out storms	177 w/out storms	163 - w/out storms	175 w/out storms	198-single w/storm	198-single w/storm	208-single w/out storm	201 - single w/out storm
Sliding Door (ft^2)	-----	-----	13	17	31	26	28	34
EXT. (WOOD) DOOR - ft^2	56-w/out storms	63 w/out storms	59 w/out storms	54 w/out storms	68 with storms	76 with storms	69 w/out storms	63 w/out storms
EXT. WALL CONSTRUCTION	Wood Frame	Wood Frame	Wood Frame	Wood Frame	Wood Frame	Wood Frame	Wood Frame	Wood Frame
Ext. Finish	Wood Siding	Wood Siding	Brick Veneer	Stucco	Wood Siding	Wood Siding	Brick Veneer	Stucco
Sheathing	Wood	Wood	Wood	none	1/2" plywood	1/2" fiberboard	1/2" fiberboard	none
Int. Finish	Plaster	Plaster	1/2" gypsumboard	Plaster	1/2" gypsumboard	1/2" gypsumboard	1/2" gypsumboard	1/2" gypsumboard
Insulation	none	none	none	none	3 1/2" Batt, R-11	3 1/2" Batt, R-11	3 1/2" Batt, R-11	3 1/2" Batt, R-11
EXT. WALL BELOW GRADE	12" concrete block	12" concrete block	none	none	12" concrete block	12" concrete block	none	none
CEILING INSULATION	4" loose fill, R-9	4" loose fill, R-9	none	none	6" Batt, R-19	6" loose fill, R-13	6" loose fill, R-13	6" Batt, R-19
FLOOR CONSTRUCTION	Wood Frame	Wood Frame	Wood Frame	Wood Frame	Wood Frame	Wood Frame	4" concrete slab	4" concrete slab
Sheathing	----	Wood	----	Wood	5/8" plywood	3/4" plywood	----	----
Underlayment	----	----	----	----	none	none	----	----
Finish	Hardwood	Hardwood	Hardwood	Carpet	Carpet	Carpet	Carpet	Carpet
Insulation	none	none	none	none	none	none	No Slab Perimeter Insulation	No Slab Perimeter Insulation
BOTTOM/ BASEMENT FLOOR	4" concrete slab	4" concrete slab	----	----	4" concrete slab	4" concrete slab	----	----

Table A-4. Single Family (New) Construction Characteristics/Resistance

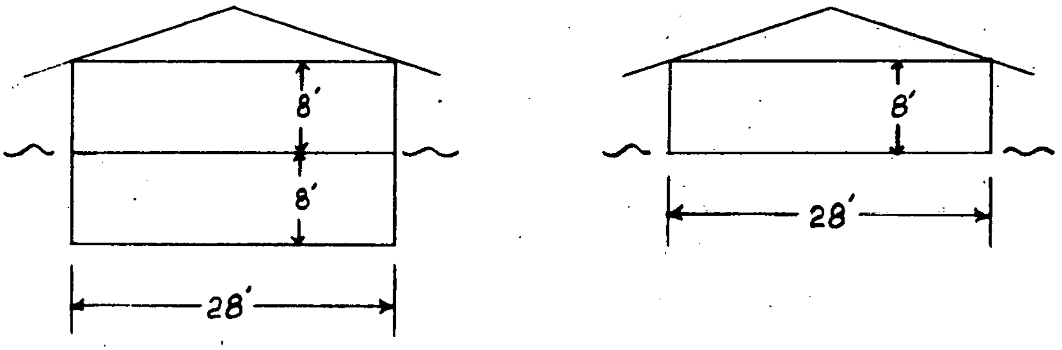
Surface	Region	Construction Description	R-Value
Exterior Wall	NE, NC	Wood siding	0.81
		1/2" fiberboard	1.32
		3 1/2" insulation	11.
		2x4 studs	4.35
		1/2" gypsum board	0.45
	S	Brick veneer	0.44
		1/2" fiberboard	1.32
		3 1/2" insulation	11.
		2x4 studs	4.35
		1/2" gypsum board	0.45
	W	Stucco 5/8"	0.13
		3 1/2" insulation	11.
		2x4 studs	4.35
		1/2" gypsum board	0.45
Ceiling		Insulation	
	NE	6" Batts	19
	NC	6" loose fill	13
	S	6" loose fill	13
	W	6" Batts	19
		2x6 rafters	6.85
		1/2" gypsum board	.45
Windows*	NE, NC	Single pane with storms	1.79
	S, W	Single pane without storms	.88
Sliding Glass Door*	NE, NC S, W	Double pane, 1/4" air space(Metal Frame0	1.40
***R values include surface resistances**			
Door*	NC	1 1/2" solid wood door, with Wood/glass storm door	3.70
	NE, S, W	1 1/2" solid wood door	2.04
Walls Below Grade	NE, NC	12" concrete blocks including earth	14.29
		3/4" styrofoam and furring	3.00
		1/2" gypsum board	.45
	S, W	No Basement	-
Basement/ Bottom Floor	NE, NC S, W	Carpet and pad	2.08
		4" concrete	.32
***R values include surface resistances**			

Table A-5. Single Family (Existing) Construction Characteristics/Resistance

Surface	Region	Construction Description	R-Value
Exterior Wall	NE, NC	Wood siding, 1/2"x8" lapped	0.81
		1/2" wood sheathing	1.32
		3 1/2" air space	0.97
		Gypsum plaster 3/4"	0.47
	S	Brick veneer (face brick) 4"	0.44
		1/2" wood sheathing	1.32
		3 1/2" air space	0.97
		1/2" gypsum board	0.45
	W	Stucco 5/8"	0.13
		3 1/2" air space	0.97
		Plaster	0.47
Ceiling		Insulation	
	NE	4" loose fill	9
	NC	4" loose fill	9
	W	none	0
	S	none	0
		2x6 Rafters	6.85
		Metal Lath and Plaster (3/4")	.47
Windows *	NE, NC, S, W	Single Pane	.88
Sliding Glass Door *	S, W,	Single pane (wood frame)	0.93
	NE, NC	None	-
Door *	NE, NC, S, W	1 1/2" solid wood door	2.04
*R values include surface resistances			
Walls Below Grade	NE, NC	12" concrete block including earth	14.29
	S, W	Crawl space	-
Basement/ Bottom Floor	NE, NC	4" concrete slab	.32
	W	Carpet and Pad	2.08
		3/4" plywood subfloor	.93
	S	3/4" hardwood floor	.68
		3/4" plywood subfloor	.93



FLOOR PLAN

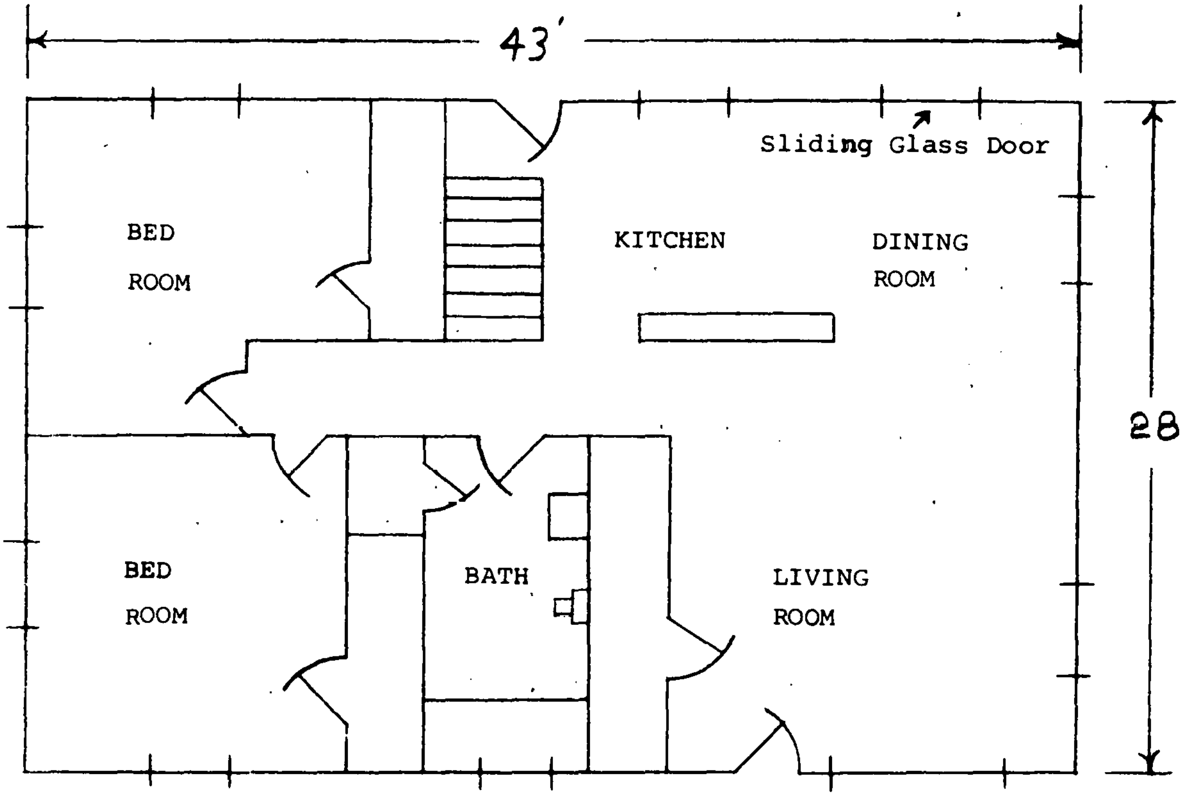


NORTH-EAST &
NORTH-CENTRAL

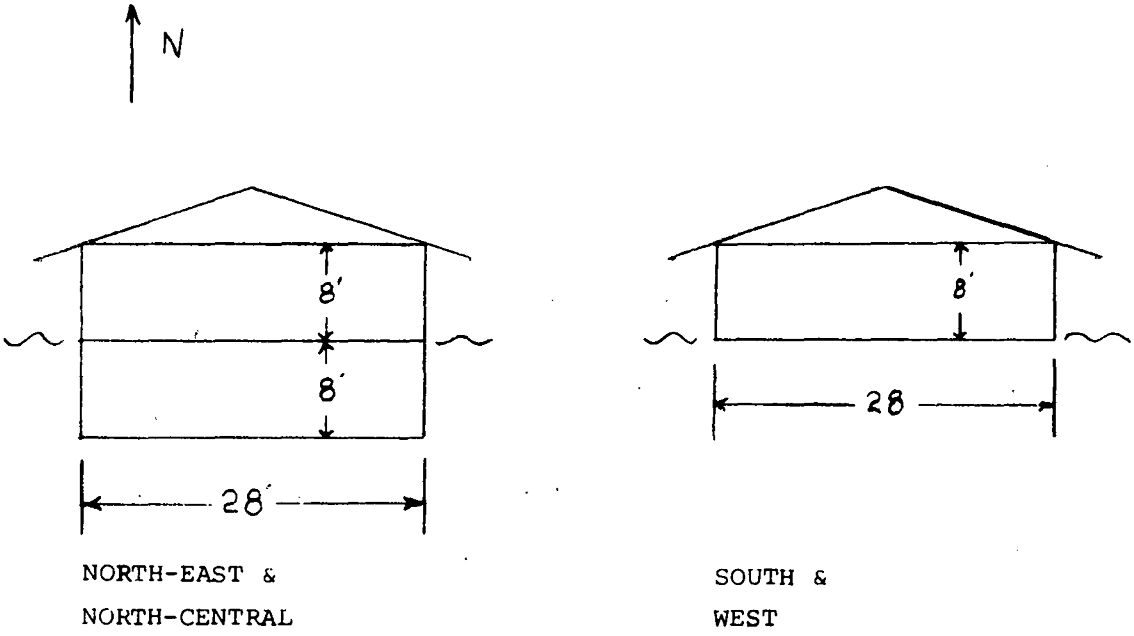
SOUTH &
WEST

ELEVATION

Figure A-1. New Single Family



FLOOR PLAN



NORTH-EAST &
NORTH-CENTRAL

SOUTH &
WEST

ELEVATION

Figure A-2. Existing Single Family

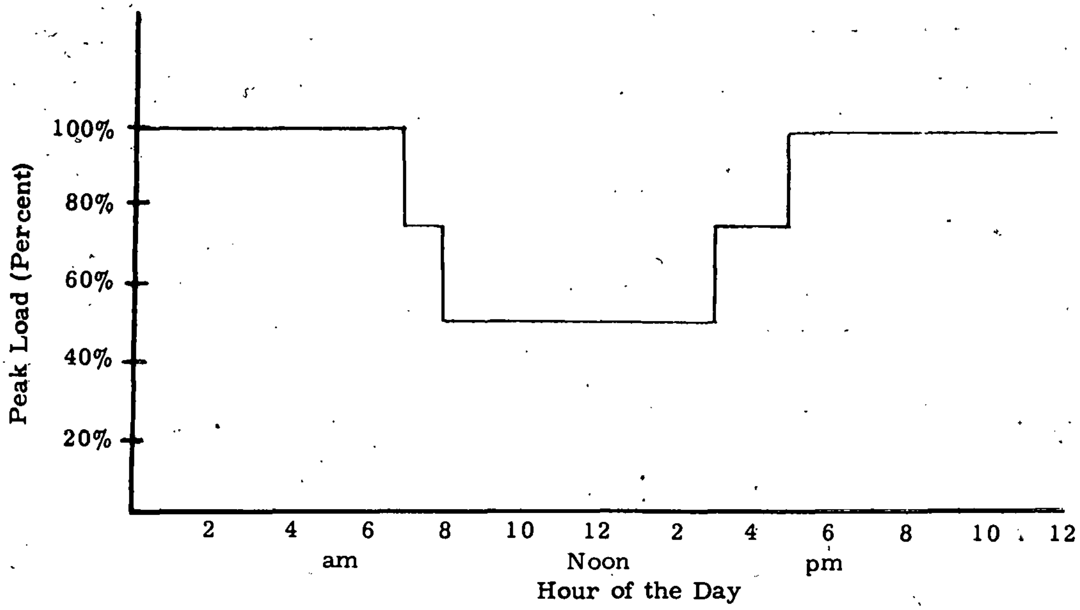


Figure A-3. Single Family Residence People Load Schedule

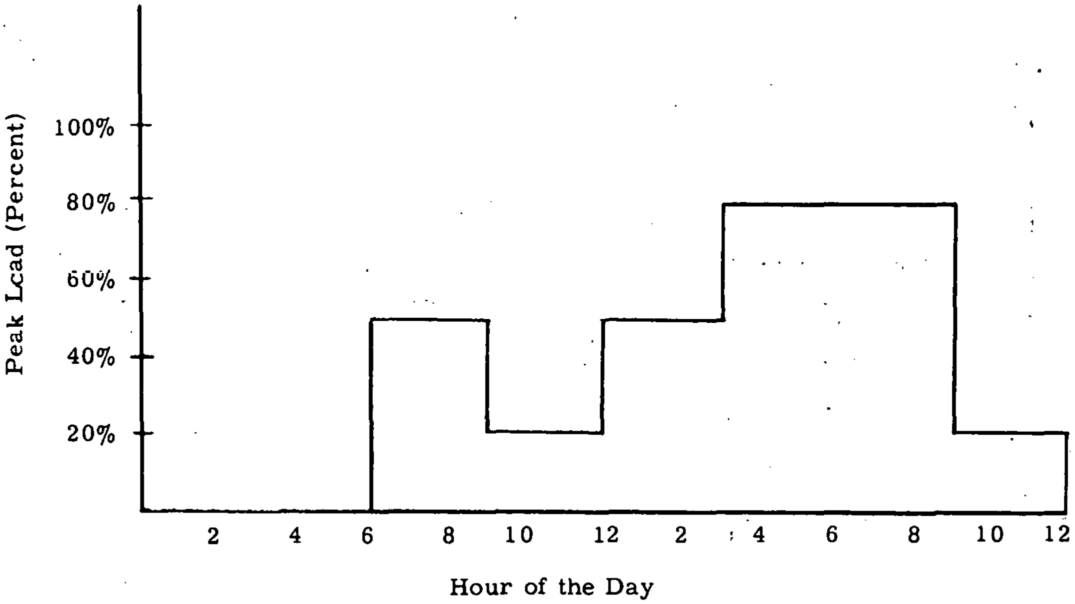


Figure A-4. Single Family Residence Lighting Schedule

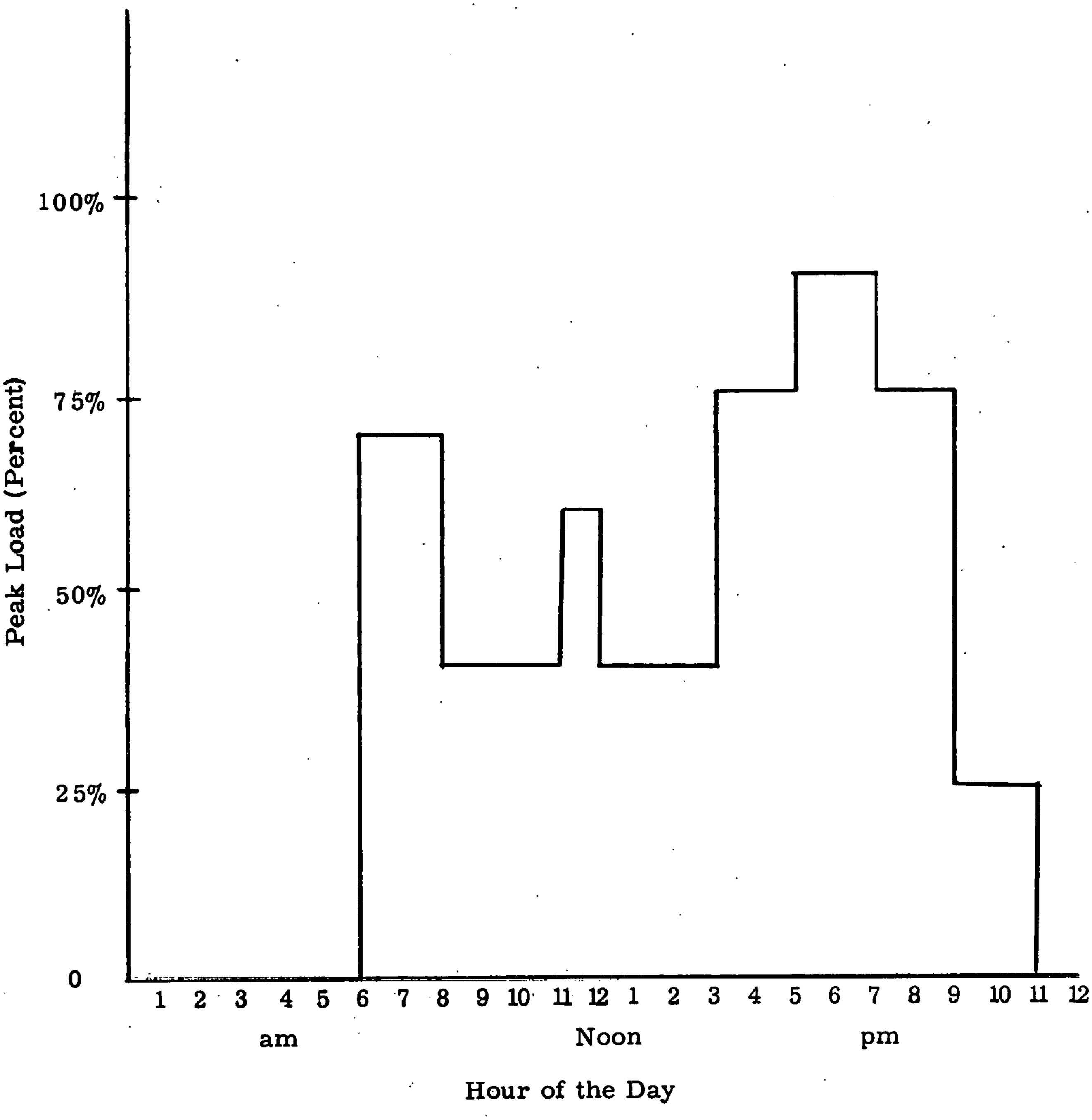
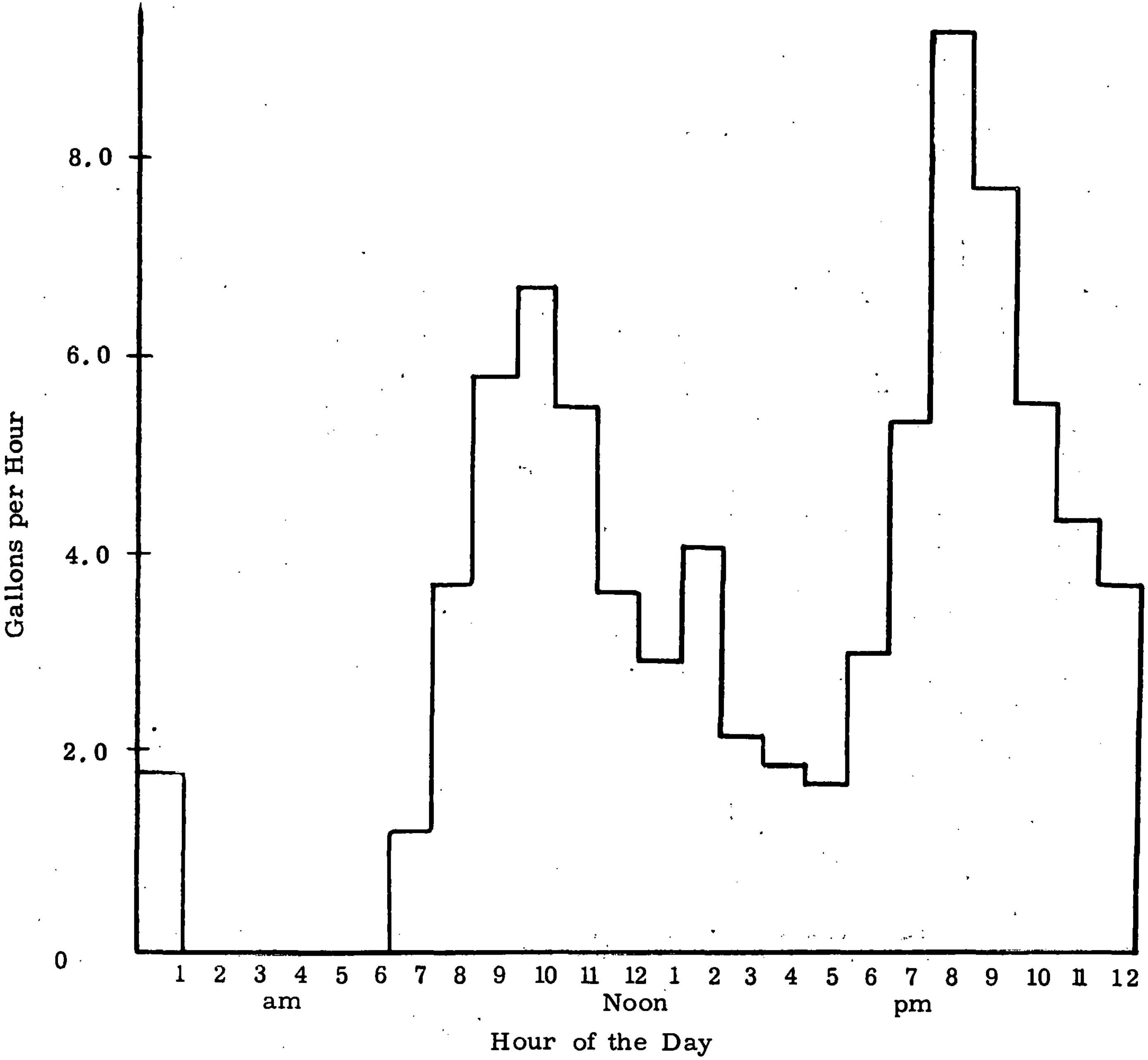


Figure A-5. Single Family Residence Appliance Schedule



*Residential Water Heating: Fuel conservation, economics, and public policy, prepared for the National Science Foundation, Rand Corporation, R-1498-NSF, May 1974, James J. Mutch.

FigureA-6. Single Family Residence Hot Water Schedule*

MULTI-FAMILY RESIDENCE

Construction characteristics used to determine heating/cooling loads for multi-family residences are summarized in Table A-6. Characteristics of new multi-family residences were extracted from information supplied by National Association of Home Builders, Research Foundation Inc. (Appendix H). Information describing characteristics of existing multi-family dwelling was not readily available in existing literature or available surveys. Data presented in Table A- 6 is based on reasonable estimates derived from descriptions provided for existing single family residences. Characteristics of new multi-family residences are based on surveys of apartments built in 1970 and 1975.

The following data for multi-family residences follows:

- New and Existing Construction Characteristics
- New and Existing Construction Thermal Resistance
- Floor Plan and Elevation
- People Load Schedule
- Lighting Load Schedule
- Appliance Load Schedule
- Hot Water Use Schedule

Table A-6. New and Existing Multi-Family Residence Construction Characteristics

CHARACTERISTIC	EXISTING				NEW			
	NORTHEAST	NORTH CENTRAL	SOUTH	WEST	NORTHEAST	NORTH CENTRAL	SOUTH	WEST
Size - ft^2/ft	4802	4802	4802	4802	4802	4802	4802	4802
Dimensions	49'x98'	49'x98'	49'x98'	49'x98'	49'x98'	49'x98'	49'x98'	49'x98'
No. of Floors	4	4	3	3	3	3	3	3
Height of Story	8'	8'	8'	8'	8'	8'	8'	8'
Foundation Type	Full Basement	Full Basement	Slab	Slab	1/2 Basement	1/2 Basement	Slab	Slab
Roof Type	Gable	Gable	Gable	Flat	Gable	Gable	Gable	Flat
No. Units/Floor	4	4	4	4	4	4	4	4
EXT. GLASS,								
Windows (ft^2/unit)	57 - Single	59 - Single	61 - Single	59 - Single	12 - Insul.	12 - Insul.	12 - Single	12 - Single
Sliding Door (ft^2/unit)	none	none	36 - Single	36 - Single	8 - Insul.	8 - Insul.	12 - Single	12 - Single
BLDG. ENTRANCE DOOR (ft^2)	20 Wood	20 Wood	20 Wood	20 Wood	20 - Insul. Metal	20 - Insul. Metal	20 Wood	20 Wood
EXT. WALLS: CONSTRUCTION	Wood Frame	Wood Frame	Wood Frame	Wood Frame	Wood Frame	Wood Frame	Wood Frame	Wood Frame
Ext. Finish	Brick Veneer	Brick Veneer	Brick Veneer	Brick Veneer	Brick Veneer	Brick Veneer	Brick Veneer	Stucco
Sheathing	1/2" plywood	1/2" plywood	1/2" plywood	1/2" plywood	1/2" fiberboard	1/2" fiberboard	1/2" gypsum	none
Int. Finish	1/2" plaster	1/2" plaster	1/2" plaster	1/2" plaster	1/2" gypsum	1/2" gypsum	1/2" gypsum	1/2" gypsum
Insulation	none	none	none	none	3 1/2" batt, R-11	3 1/2" batt, R-11	3 1/2" batt, R-11	3 1/2" batt, R-1
EXT. WALL BELOW GRADE	12" concrete block	12" concrete block	None	none	12" concrete block 3/4" styrofoam 1/2" gypsum	12" concrete block 4/3" styrofoam 1/2" gypsum	none	none
CEILING INSULATION	4" loose fill, R-9	4" loose fill, R-9	none	none	6" loose fill, R-13	6" loose fill, R-13	6" loose fill, R-13	6" batt, R-19
FLOOR:	Wood Frame	Wood Frame	Wood Frame	Wood Frame	Wood Frame	Wood Frame	Wood Frame	Wood Frame
Sheathing	3/4" wood	3/4" wood	3/4" wood	3/4" wood	5/8" plywood	5/8" plywood	5/8" plywood	5/8" plywood
Underlayment	----	----	----	----	none	none	none	none
Finish	Hardwood	Hardwood	Hardwood	Hardwood	Carpet	Carpet	Carpet	Carpet
Insulation	none	none	none	none	none	none	none	none
BOTTOM/ BASEMENT FLOOR	4" concrete slab	4" concrete slab	4" concrete slab	4" concrete slab	4" concrete slab	4" concrete slab	4" concrete slab	4" concrete slab

Table A-7. Multi-Family (New) Surface Construction/ Resistance Values

Surface	Region	Construction Description	R-Value
Outside Wall	NC, NE	Brick Veneer (4" face brick)	.44
		1/2" Fiberboard Sheathing	1.32
		3 1/2" Batt Insulation	11.0
		2x4 Studs, 16" O.C.	4.35
		1/2" Gypbd	.45
	S	Brick Veneer (4" face brick)	.44
		1/2" Gypbd	.45
		3 1/2" Insulation	11.0
		2x4 Studs	4.35
		1/2" Gypbd.	.45
	W	Stucco (5/8")	0.13
		3 1/2" Insulation	11
		2x4 Studs	4.35
		1/2" Gypbd	0.45
Ceiling		Insulation	
	NE	6" loose fill	13
	NC	6" loose fill	13
	S	6" loose fill	13
	W	6" Batts	19
		2x6 Rafters	6.85
		1/2" Gypbd	.45
Windows *	NC, NE	Insulated Glass	1.54
	S, W	Single Pane	.88
Sliding Glass Door*	NC, NE	Insulated Glass (Metal frame)	1.40
	S, W	Single Pane (Metal frame)	.88
Doors*	NC, NE	1 3/4" Steel Door (Solid Polystyrene Core)	2.13
	S, W	1 1/2" Solid Wood	2.04
		*R values include surface resistances	
Wall Below Grade	NE, NC	12" Concrete Block	2.27
		3/4" Insulation (and Furring)	3.0
		1/2" gypsum board	.45
Basement Floor/Slab	NE, NC S, W	Carpet (fibrous pad)	2.08
		4" Concrete Slab	.32

Table A-8. Multi-Family (Existing) Surface Construction/ Resistance Values

Surface	Region	Construction Description	R-Value
Exterior Wall	NE, NC, S, W	Brick Veneer (4" Face Brick)	.44
		1/2" Plywood Sheathing	.62
		2x4 Studs	4.35
		1/2" Plaster	.32
		Air Space	.97
Ceiling		Insulation	
	NE	4" loose fill	9.0
	NC	4" loose fill	9.0
	S	none	-
	W	none	-
		1/2" plaster	.32
		rafters	6.85
Windows*	NE, NC, S, W	Single Pane	.88
Sliding Glass Door*	S, W	Single Pane (Wood frame)	.93
	NE, NC	None	-
Doors*	NE, NC, S, W	1 ½" Wood	2.04
Walls Below Grade	NE, NC	12" Concrete Block	2.27
Bottom Floor	NE, NC	4" Concrete	.32
	S, W	Carpet and Pad	2.08
		4" Concrete	.32

* R values include surface resistances

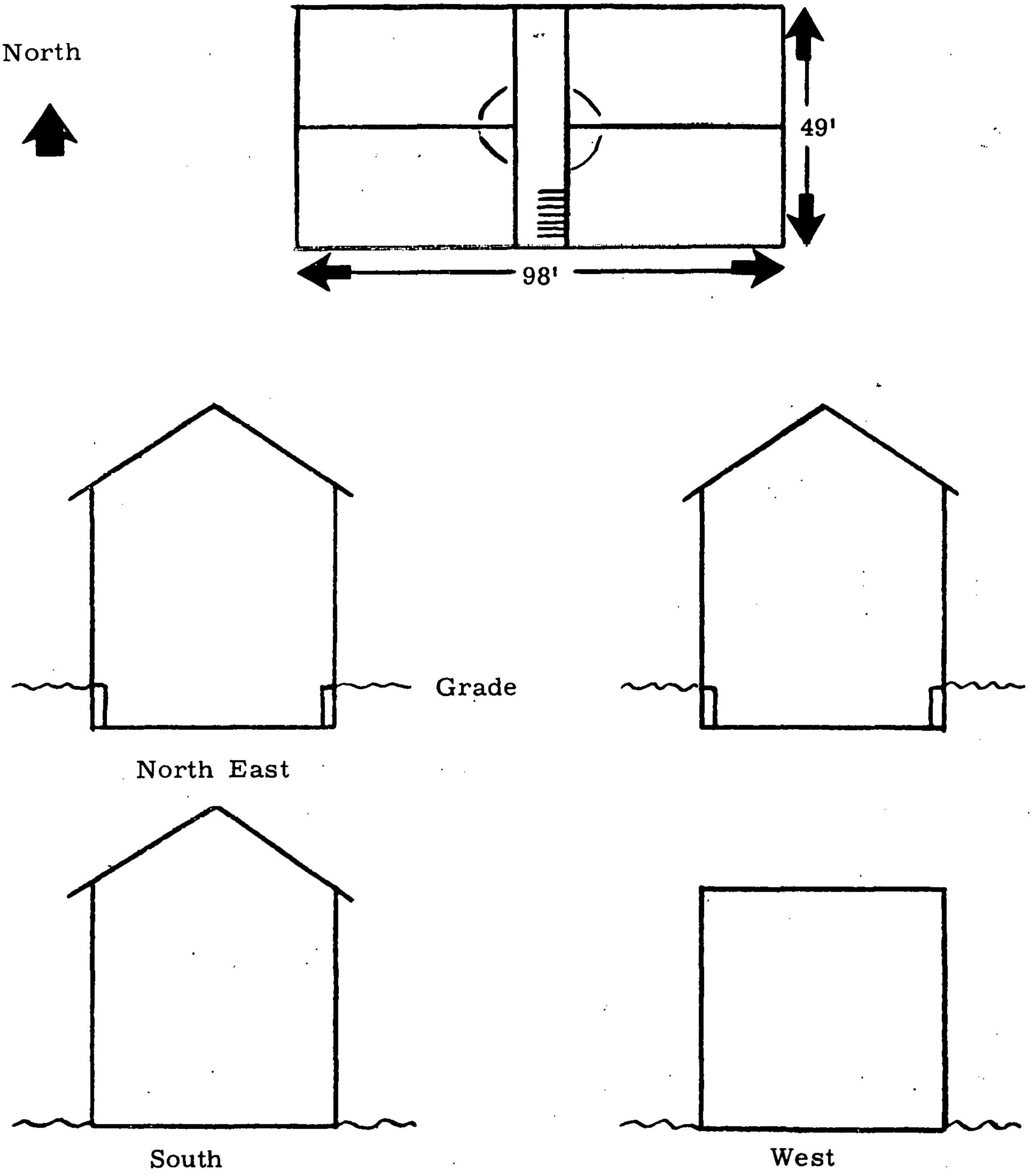


Figure A-7. Multi-Family (New) Building Profile

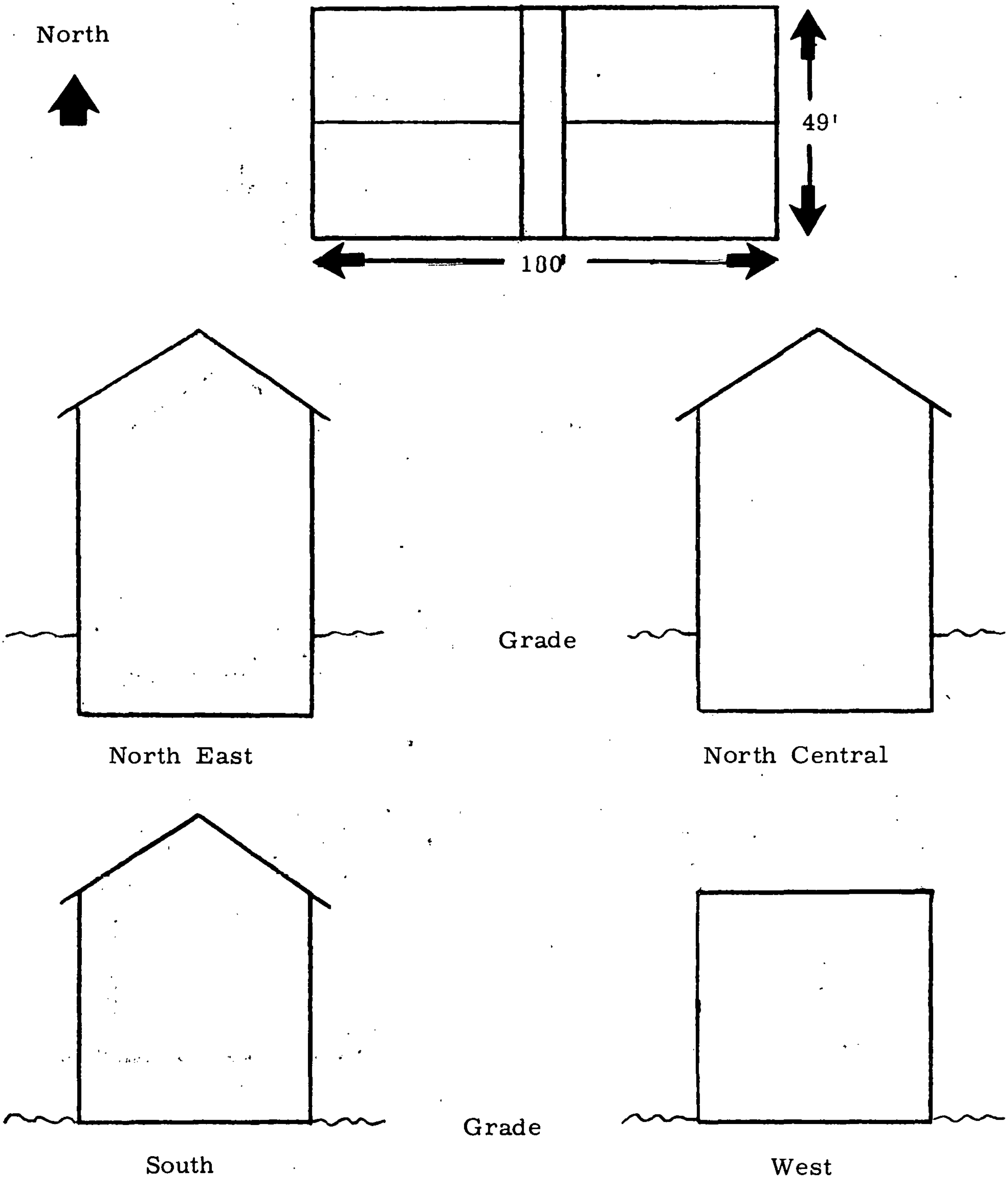
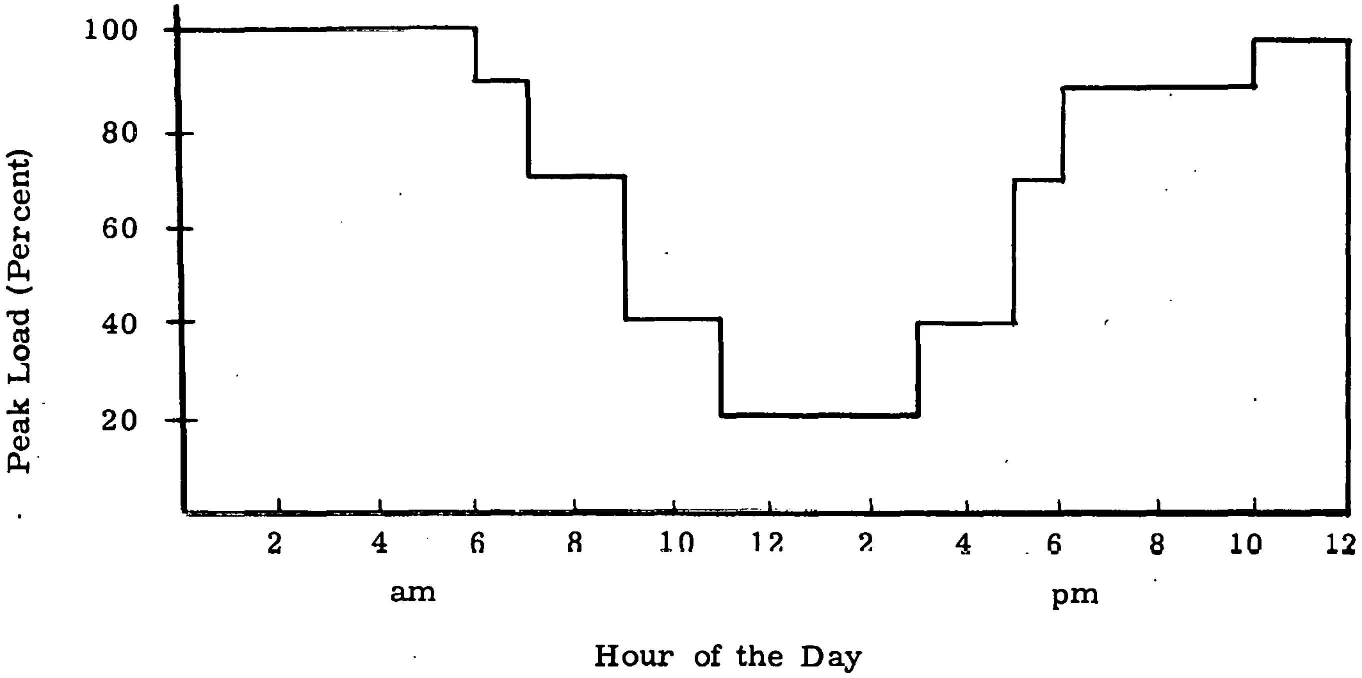
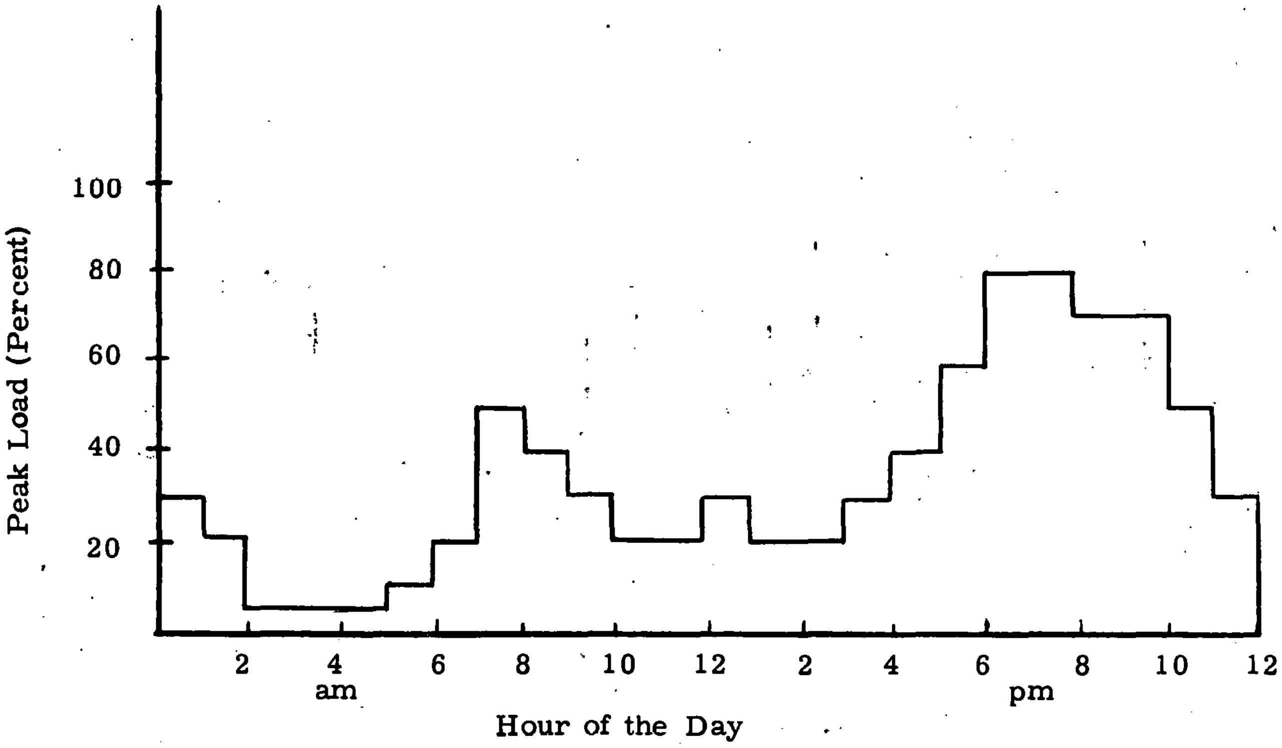


Figure A-8. Multi-Family (Existing) Building Profile



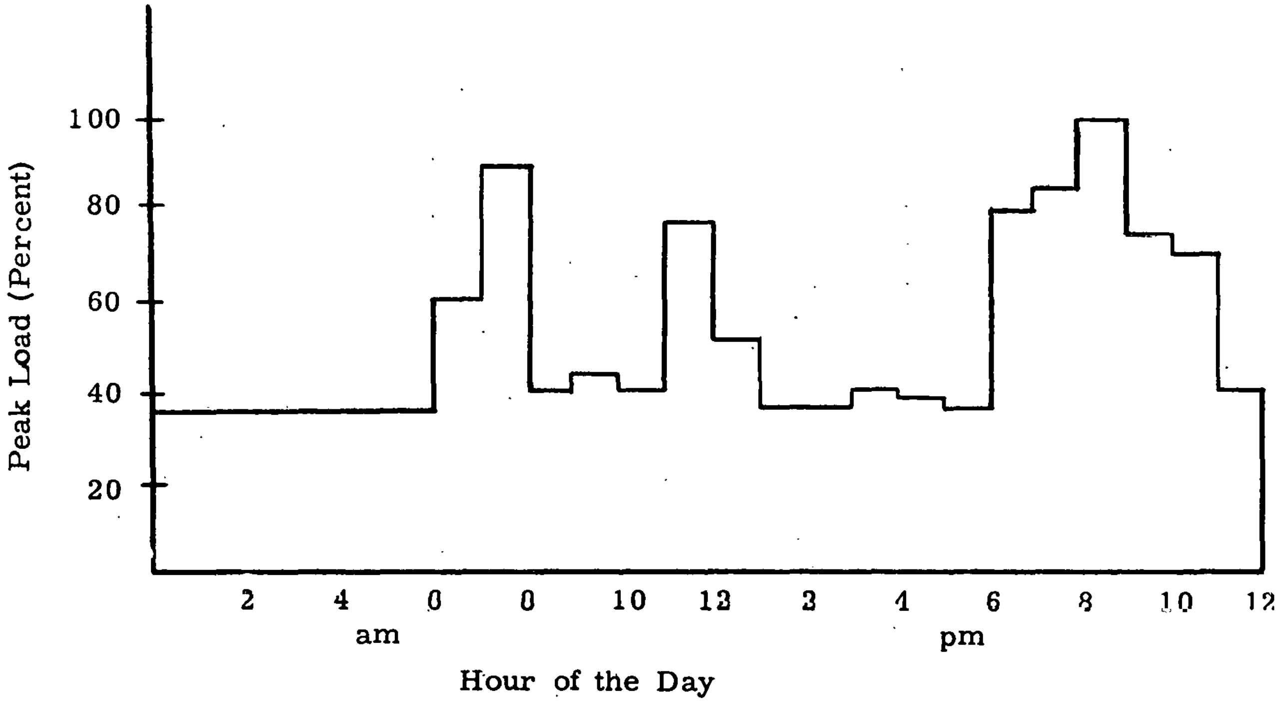
*Residential Energy Consumption - Multi-family housing final report, June 1974. Prepared for the Department of Housing and Urban Development, Hittman Associates, Inc.

Figure A-9. Multi-Family Residence People Load Schedule*



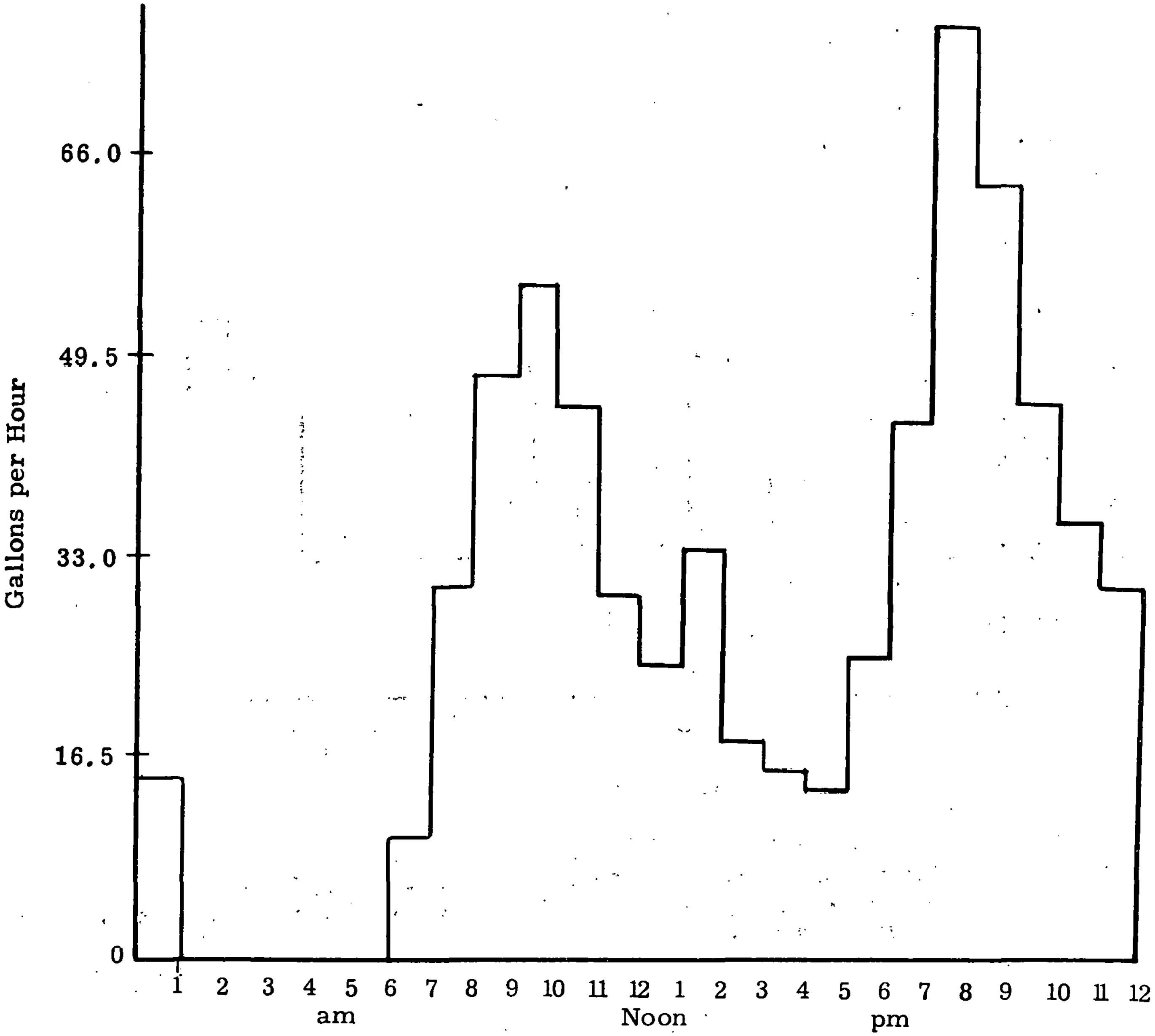
*Residential Energy Consumption - Multi-family housing final report, June 1974. Prepared for the Department of Housing and Urban Development, Hittman Associates, Inc.

Figure A-10. Multi-Family Residence Light Load Schedule*



*Residential Energy Consumption - Multi-family housing final report, June 1974. Prepared for the Department of Housing and Urban Development, Hittman Associates, Inc.

Figure A-11. Multi-Family Appliance Load Schedule*



*Residential Water Heating: Fuel conservation, economics and public policy, prepared for the National Science Foundation, Rand Corporation, R-1498-NSF, May 1974, James J. Mutch.

Figure A-12. Multi-Family Hot Water Schedule

RETAIL STORES

The data for retail store construction was pieced together primarily from information provided by David J. Bennett of Bather, Ringrose, Wolsfeld Inc. The descriptive details of the following parameters complete this section of background material.

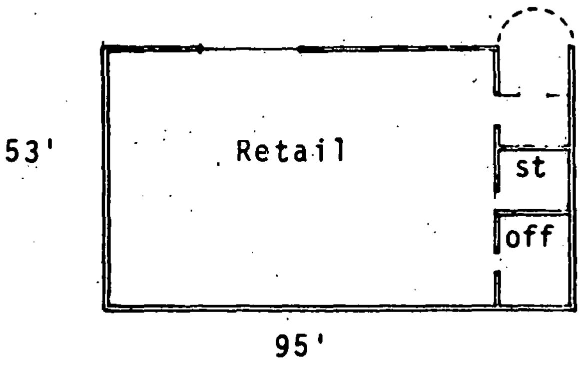
- New and Existing Construction Characteristics
- New and Existing Construction Thermal Resistance
- Floor Plan and Elevation
- People Load Schedule
- Lighting Load Schedule
- Ventilation Schedule
- Hot Water Use Schedule

Table A-9. Retail Store Construction Characteristics

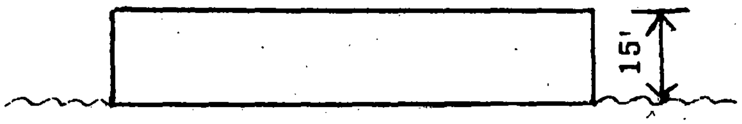
CHARACTERISTICS	EXISTING				NEW			
	NORTHEAST	NORTH CENTRAL	SOUTH	WEST	NORTHEAST	NORTH CENTRAL	SOUTH	WEST
SIZE (FT^2)	5035	5035	5035	5035	5035	5035	5035	5035
DIMENSIONS	53' x 95'	53' x 95'	53' x 95'	53' x 95'	53' x 95'	53' x 95'	53' x 95'	53' x 95'
NO. OF FLOOR	1	1	1	1	1	1	1	1
HEIGHT	15'	15'	15'	15'	15'	15'	15'	15'
FOUNDATION	4" Conc. Slab	4" Conc. Slab	4" Conc. Slab	4" Conc. Slab	4" Conc. Slab	4" Conc. Slab	4" Conc. Slab	4" Conc. Slab
ROOF (FLAT)	Built-up	Built-up	Built-up	Built-up	Built-up	Built-up	Built-up	Built-up
Deck	Metal	Metal	Metal	Metal	Metal	Metal	Metal	Metal
Insulation	None	None	None	None	2" Rigid	2" Rigid	2" Rigid	2" Rigid
EXT. GLASS (FT^2)	140	140	140	140	140	140	140	140
Type	1/4" Single	1/4" Single	1/4" Single	1/4" Single	1" insulated	1" insulated	1" insulated	1" insulated
EXT. DOORS (FT^2)	105	105	105	105	105	105	105	105
Type	1/4" Glass	1/4" Glass	1/4" Glass	1/4" Glass	1" Insulated Glass	1" Insulated Glass	1" Insulated Glass	1" Insulated Glass
EXT. WALLS	Metal Curtainwall	Masonry	Metal Curtainwall	Masonry	Metal Curtainwall	Masonry	Metal Curtainwall	Masonry
Insulation	None	None	None	None	2" Rigid	1" Rigid	2" Rigid	1" Rigid
Int. Finish	None	None	None	None	Gypbd.	None	Gypbd.	None
Area (Ft^2)	4195	4195	4195	4195	4195	4195	4195	4195

Table A-10. Office Building Construction Characteristics

CHARACTERISTIC	EXISTING				NEW			
	NORTHEAST	NORTH CENTRAL	SOUTH	WEST	NORTHEAST	NORTH CENTRAL	SOUTH	WEST
Size - ft^2/ft	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Dimensions	100'x100'	100'x100'	100'x100'	100'x100'	100'x100'	100'x100'	100'x100'	100'x100'
No. of Floors	3	3	3	3	3	3	3	3
Height of Story	12'	12'	12'	12'	12'	12'	12'	12'
Foundation Type	4" slab	4" slab	4" slab	4" slab	4" slab	4" slab	4" slab	4" slab
Roof Type (Flat	Built up, metal deck	Built up, metal deck	Build up, metal deck	Build up, metal deck	Build up, metal deck	Build up, metal deck	Build up, metal deck	Build up, metal deck
Insulation	none	none	none	none	2" rigid	2" rigid	2" rigid	2" rigid
EXT. GLASS (ft^2)	4320	4320	4320	4320	4320	4320	4320	4320
Type	1/4" single	1/4" single	1/4" single	1/4" single	1" insulated	1" insulated	1" insulated	1" insulated
EXT. DOORS (ft^2)	160	160	160	160	160	160	160	160
Type	1/4" glass	1/4" glass	1/4" glass	1/4" glass	1" ins. glass	1" ins. glass	1" ins. glass	1" ins. glass
EXT. WALL:	Metal curtainwall	Masonry	Metal Curtainwall	Masonry	Metal Curtainwall	Masonry	Metal Curtainwall	Masonry
Insulation	none	none	none	none	2" rigid	1" rigid	2" rigid	1" rigid
Int. Finish	none	none	none	none	Gypsumboard	none Gypsumbd.	Gypsumboard	gypsumbd.
Area (ft^2)	10,080	10,080	10,080	10,080	10,080	10,080	10,080	10,080

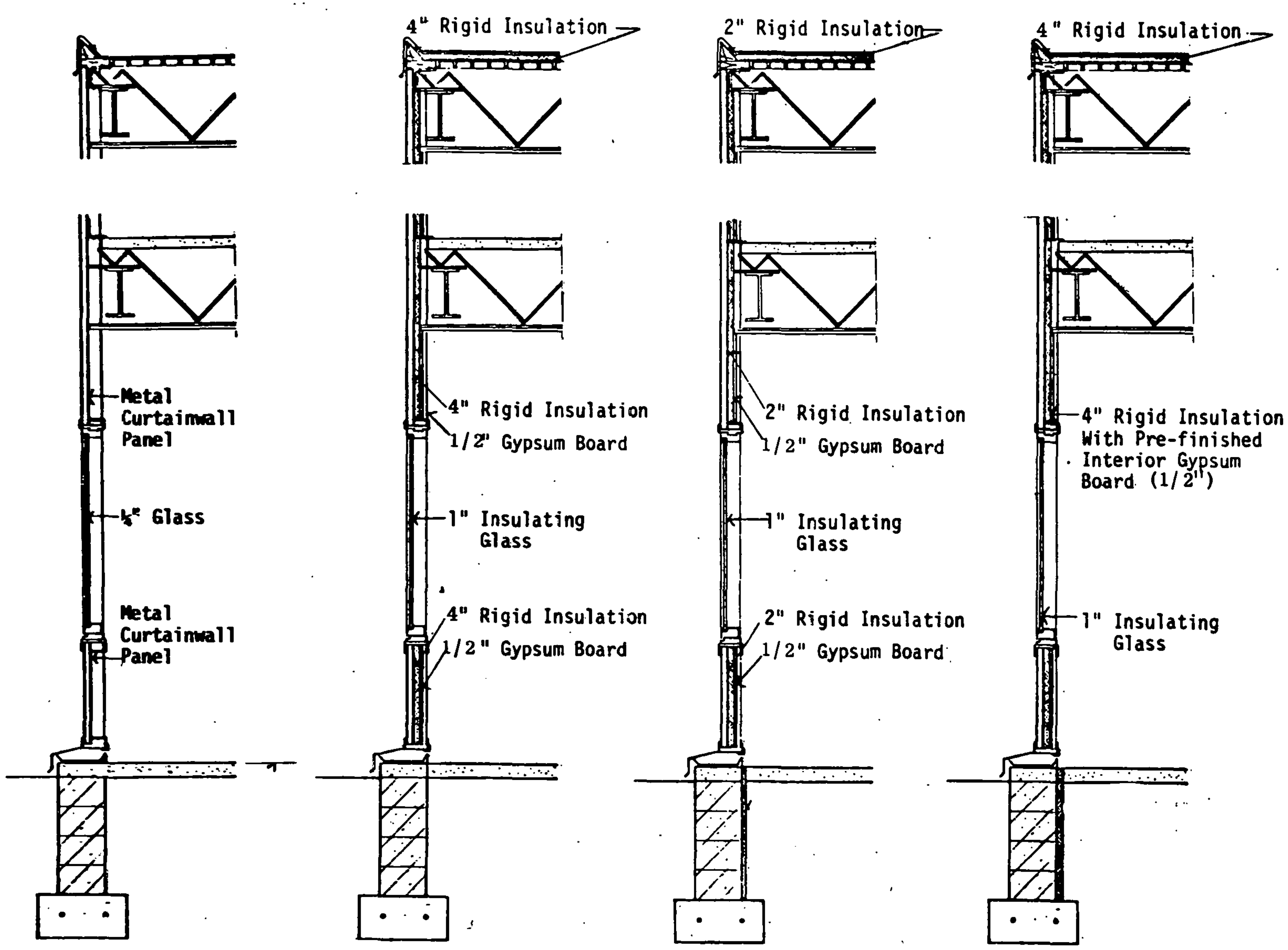


Plan View



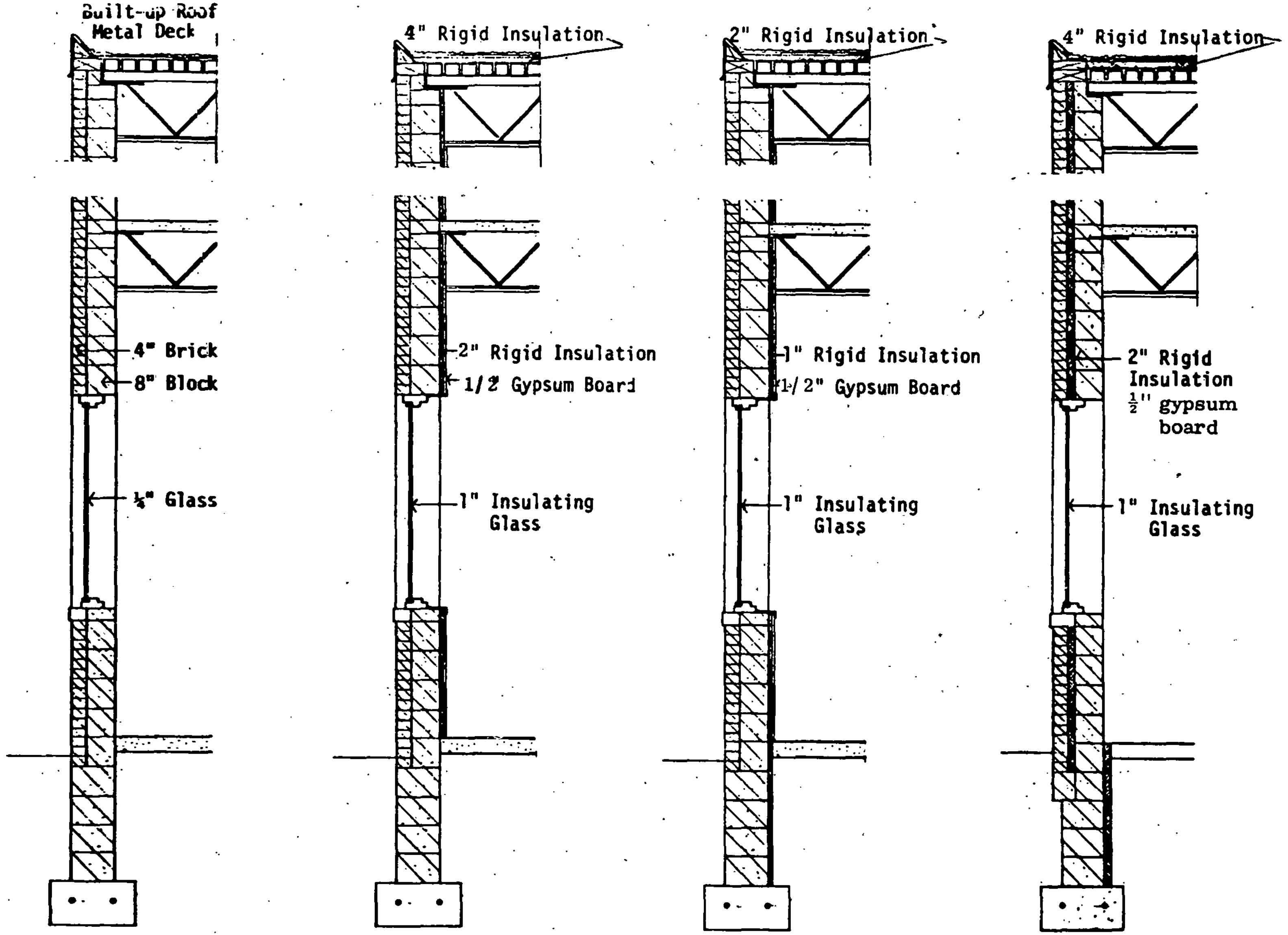
Elevation

Figure A-13. Retail Store Plan and Elevation



Existing Base Case　Existing-Improved　New-Base Case　New-Improved

Figure A-14. Retail Store Curtain Wall Construction (Northeast and South)



Existing-Base Case Existing-Improved New-Base Case New-Improved

Figure A-15. Retail Store Masonry Construction (North Central and West)

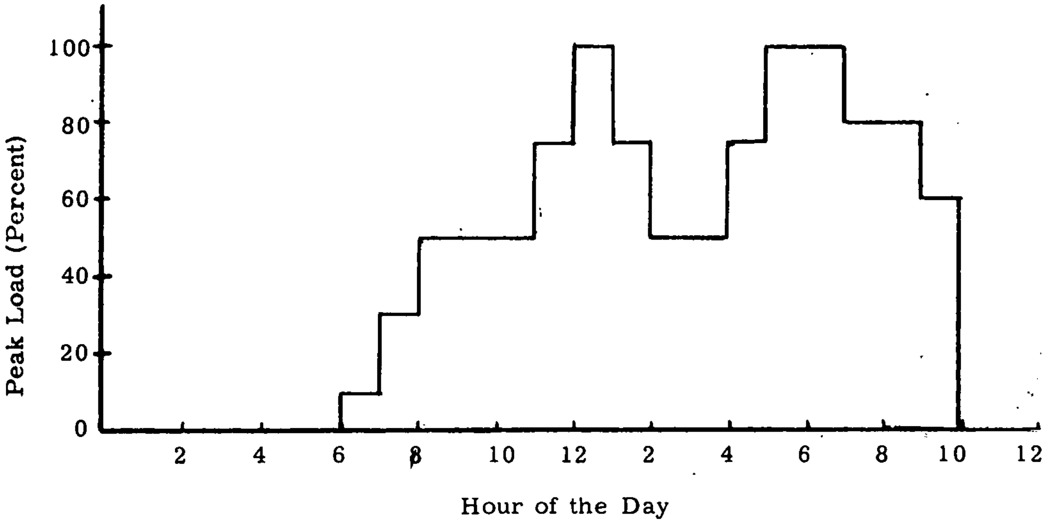


Figure A-16. Retail Store People Load Schedule

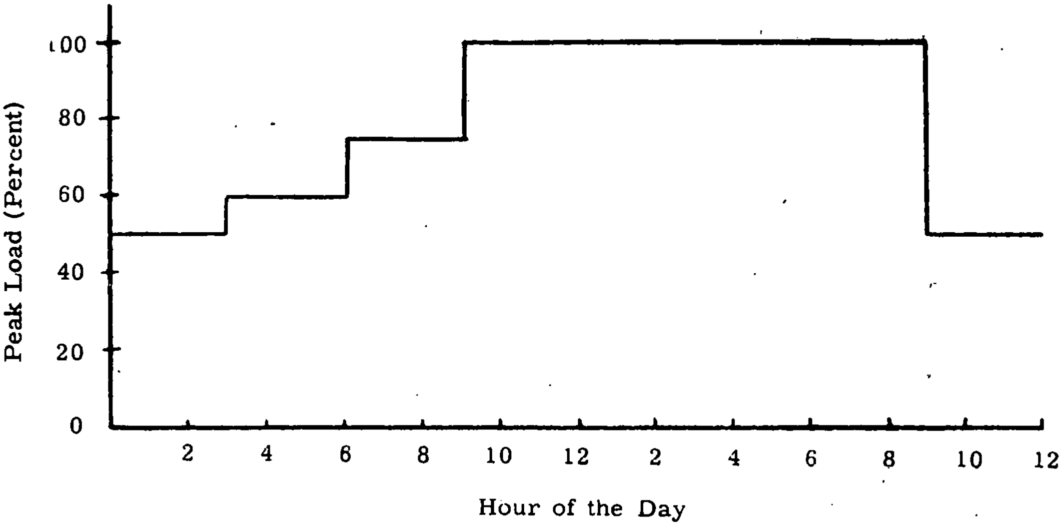


Figure A-17. Retail Store Lighting Use Schedule

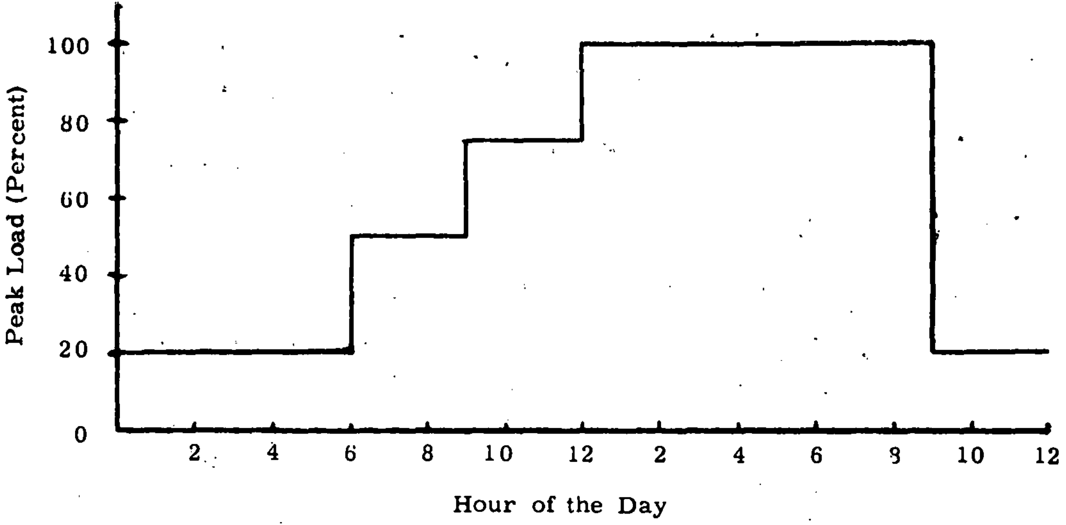


Figure A-18. Retail Store Ventilation Schedule

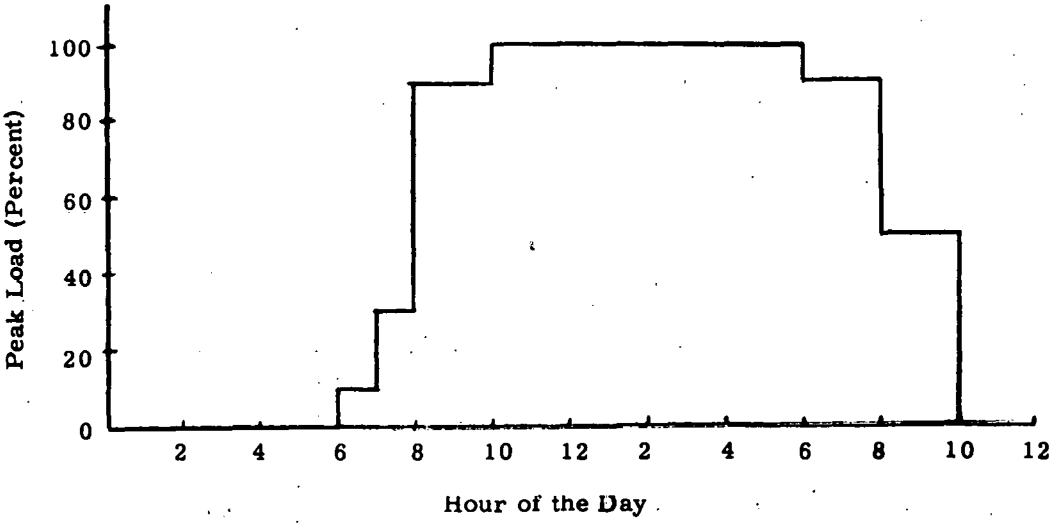


Figure A-19. Retail Store Hot Water Schedule

OFFICE BUILDINGS

The data for office building construction was pieced together primarily from information provided by David J. Bennett of Bather, Ringrose, Wolsfeld Inc. The descriptive details of the following parameters complete this section of background material.

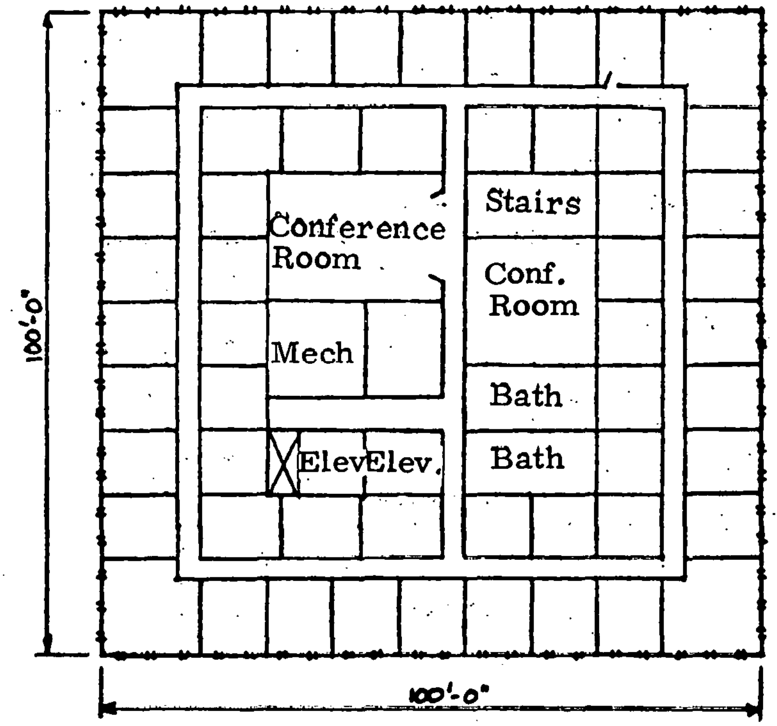
- New and Existing Construction Characteristics
- New and Existing Construction Thermal Resistance
- Floor Plan and Elevation
- People Load Schedule
- Lighting Load Schedule
- Ventilation Schedule
- Hot Water Use Schedule

Table A-11. Retail Store Construction Thermal Resistance

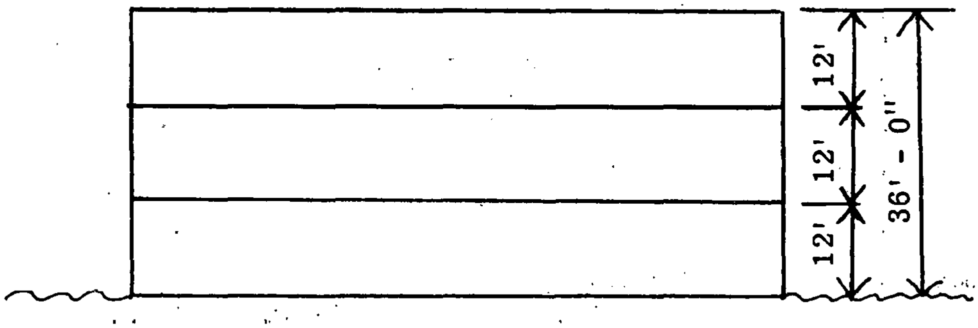
Surface	Region	Construction Description	R-Value
ROOF	N.E., N.C. S., W.	EXISTING:	
		3/8" Built-up Roof	0.33
		Metal Deck	0
		NEW:	
		3/8" Built-up Roof	0.33
		2" Roof Insulation	5.56
		Metal Deck	0
WALLS	N.E., S.	EXISTING:	
		2" Metal Curtainwall	2.00
		NEW:	
		2" Metal Curtainwall	2.00
		2" Rigid Insulation w/	8.00
		Prefinished Gypsum Board (1/2")	0.45
	N.C., W.	EXISTING:	
		4" Face Brick	0.44
		8" Conc. Block	2.00
		NEW:	
		4" Face Brick	0.44
		1" Rigid Insulation	4.00
		8" Concrete Block	2.00
		½" gypsum board	.45
GLASS* Windows/ Door	N.E., N.C. S., W.	EXISTING:	
		1/4" Single Light	.88
*R values include surface resistances		NEW:	
		1" Insulating Glass (Double - 1/2" air)	1.72
Basement Bottom Floor	N.E., N.C. S., W	4" Concrete Slab	.48

Table A-12. Office Building Construction Thermal Resistance

Surface	Region	Construction Description	R-Value
ROOF	N.E., N.C. S., W.	EXISTING:	
		3/8" Built-up Roof	0.33
		Metal Deck	0
		NEW:	
		3/8" Built-up Roof	0.33
		2" Roof Insulation	5.56
		Metal Deck	0
WALLS	N.E., S.	EXISTING:	
		2" Metal Curtainwall	2.00
		NEW:	
		2" Metal Curtainwall	2.00
		2" Rigid Insulation w/	8.00
		Prefinished Gypsum Board (1/2")	0.45
	N.C., W.	EXISTING:	
		4" Face Brick	0.44
		8" Conc. Block	2.00
		NEW:	
		4" Face Brick	0.44
		1" Rigid Insulation	4.00
		8" Concrete Block	2.00
		½" gypsumboard	.45
GLASS * Windows/ Door	N.E., N.C. S., W.	EXISTING:	
		1/4" Single Light	.88
* R values include surface resistances		NEW:	
		1" Insulating Glass (Double - 1/2" air)	1.72
Basement Bottom Floor	N.E., N.C. S., W	4" Concrete Slab	.48

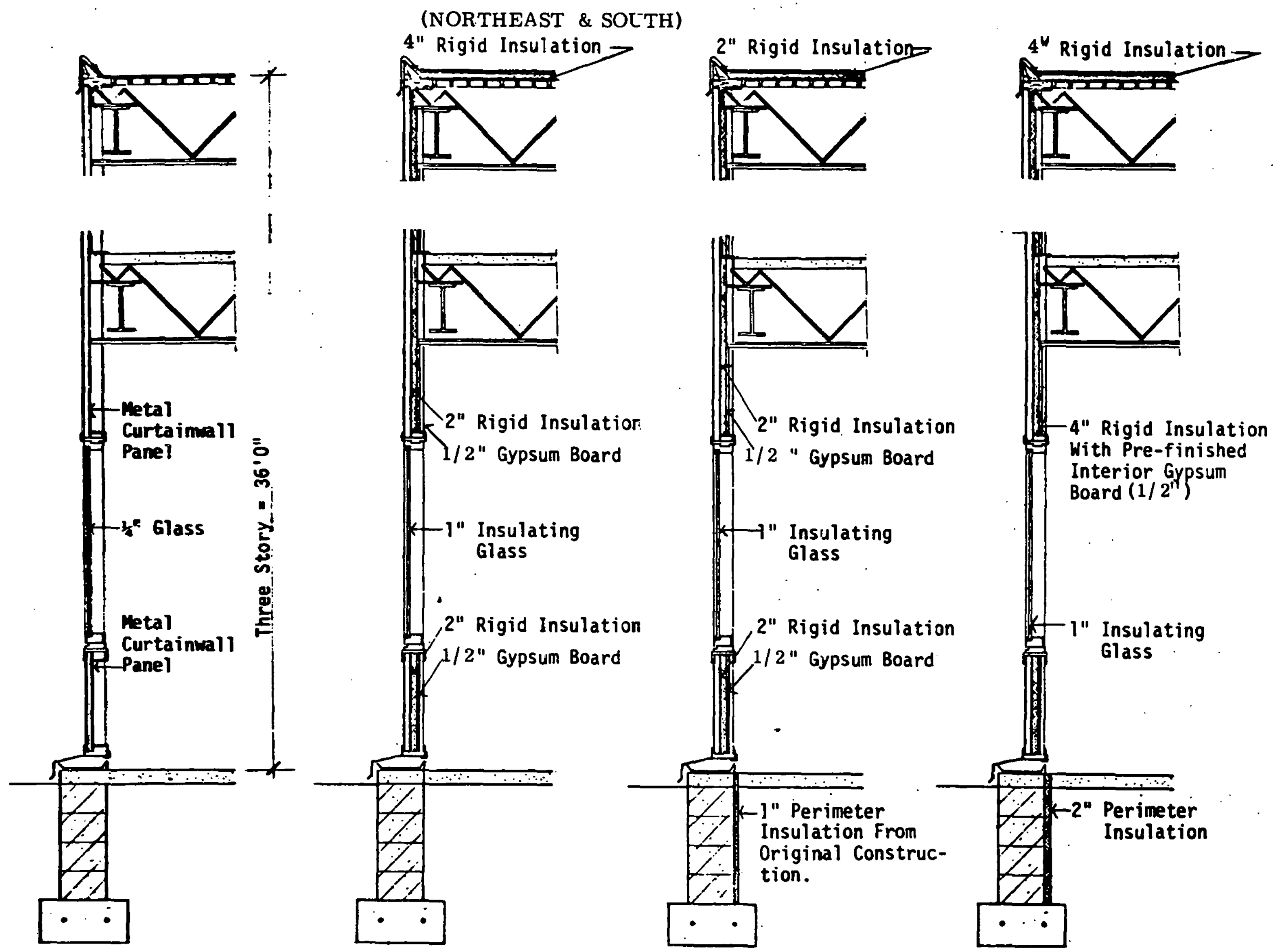


Plan View



Typical Elevation

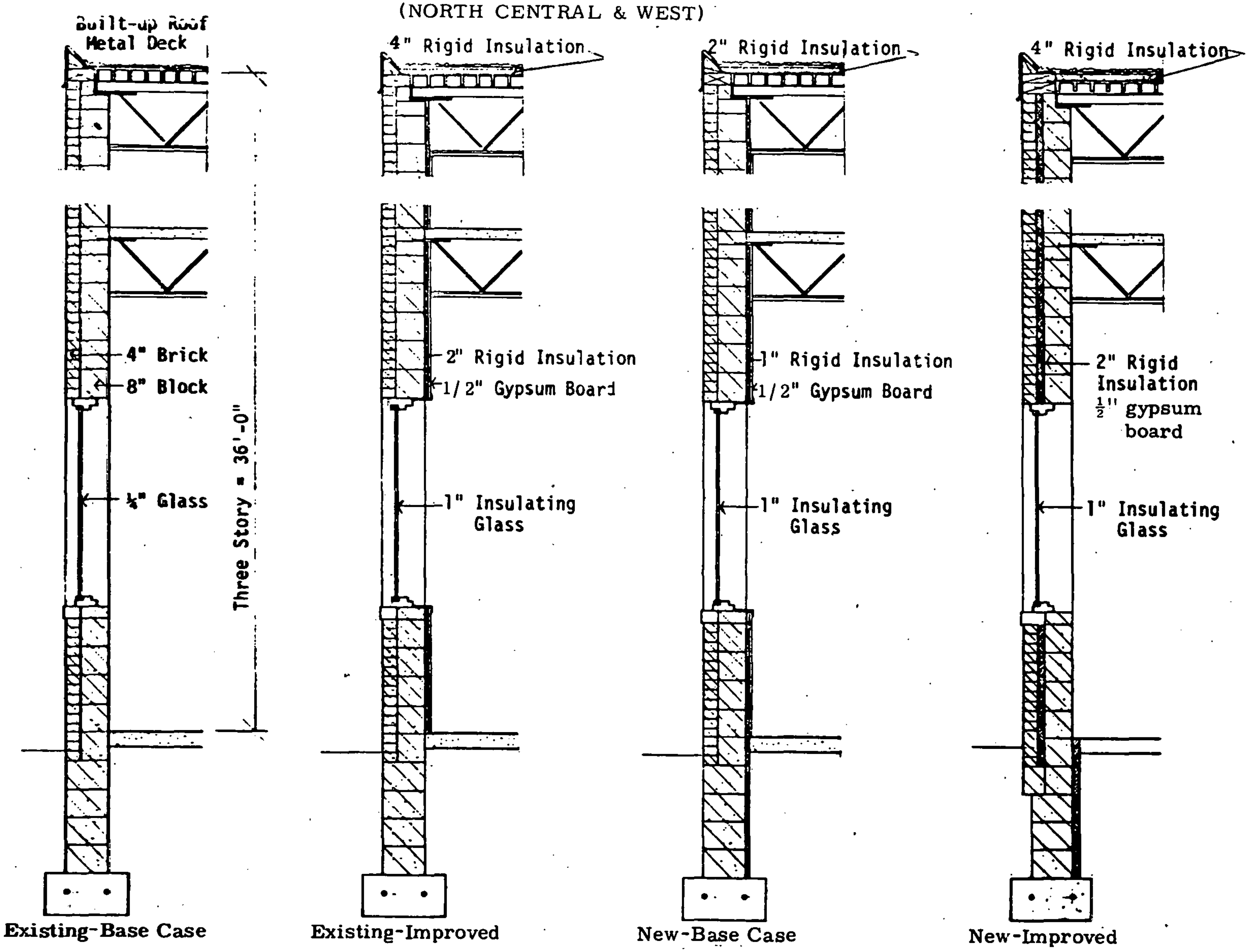
Figure A-20. Office Building Plan and Elevation



Existing-Base Case Existing-Improved New-Base Case New-Improved

Figure A-21. Curtain Wall Construction - Office Building - Three Story

(NORTH CENTRAL & WEST)



Existing-Base Case

Existing-Improved

New-Base Case

New-Improved

Figure A-22. Masonry Construction - Office Building - Three Story

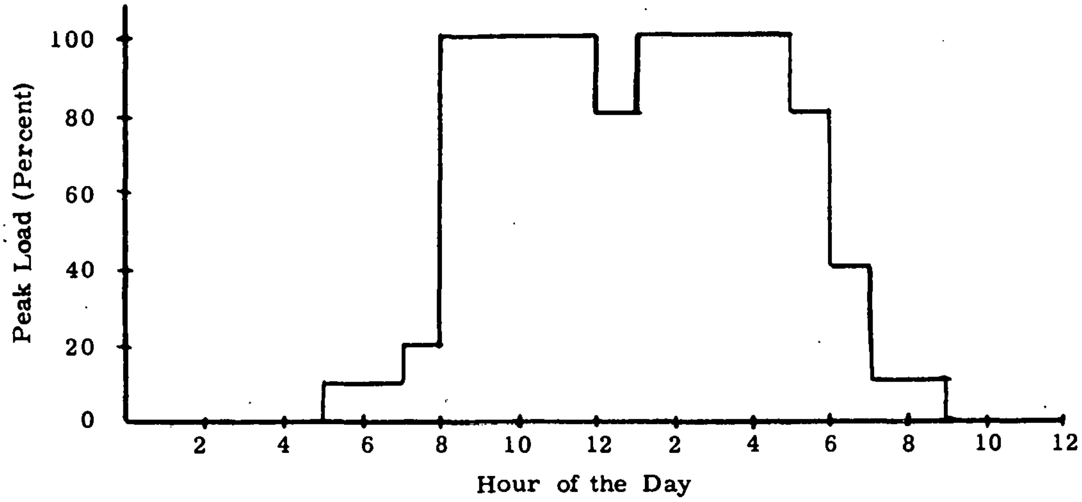


Figure A-23. Office Building People Load Schedule

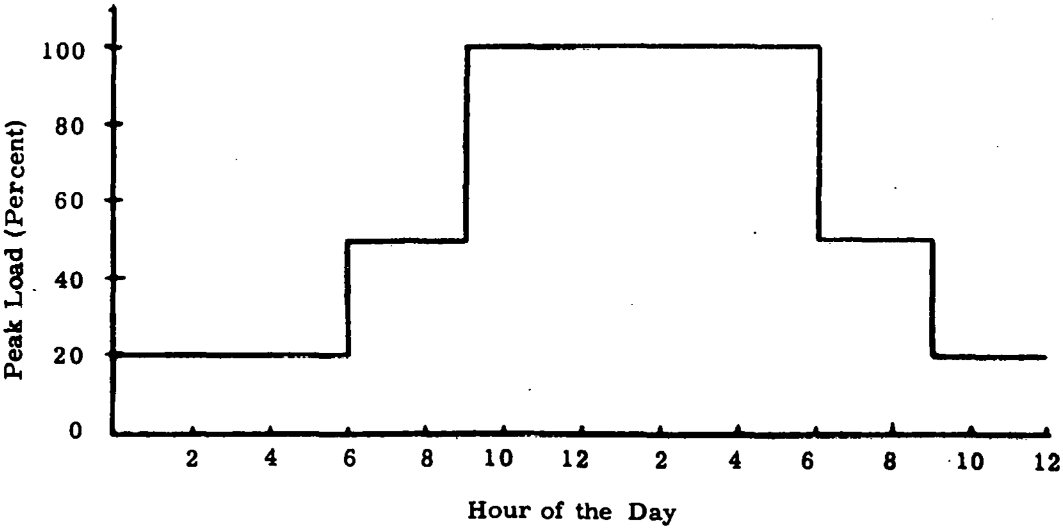


Figure A-24. Office Building Light Schedule

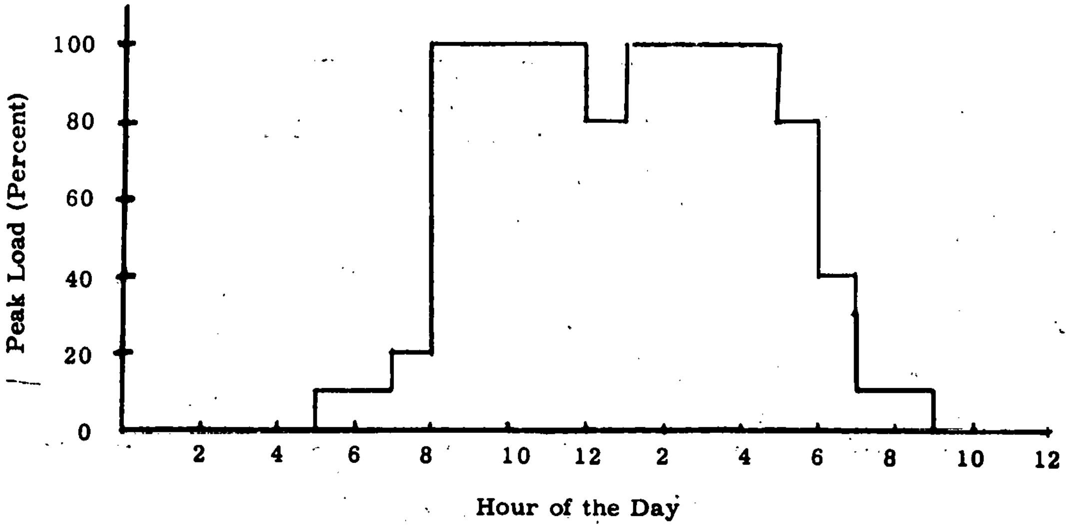


Figure A-25. Office Building Hot Water Schedule

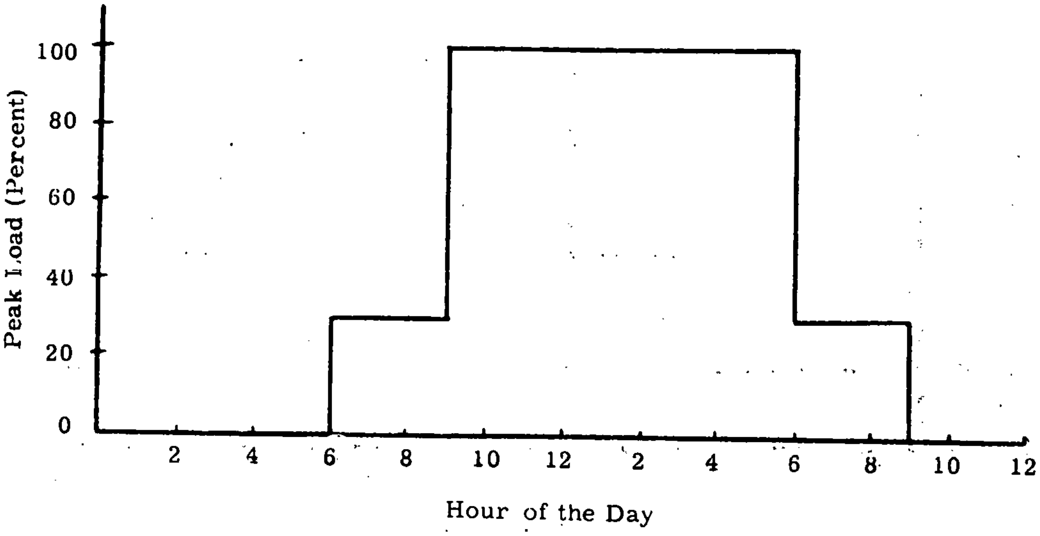


Figure A-26. Office Building Ventilation Schedule

SCHOOL BUILDINGS

The data for school building construction was pieced together primarily from information provided by David J. Bennett of Bather, Ringrose, Wolsfeld Inc. The descriptive details of the following parameters complete this section of background material.

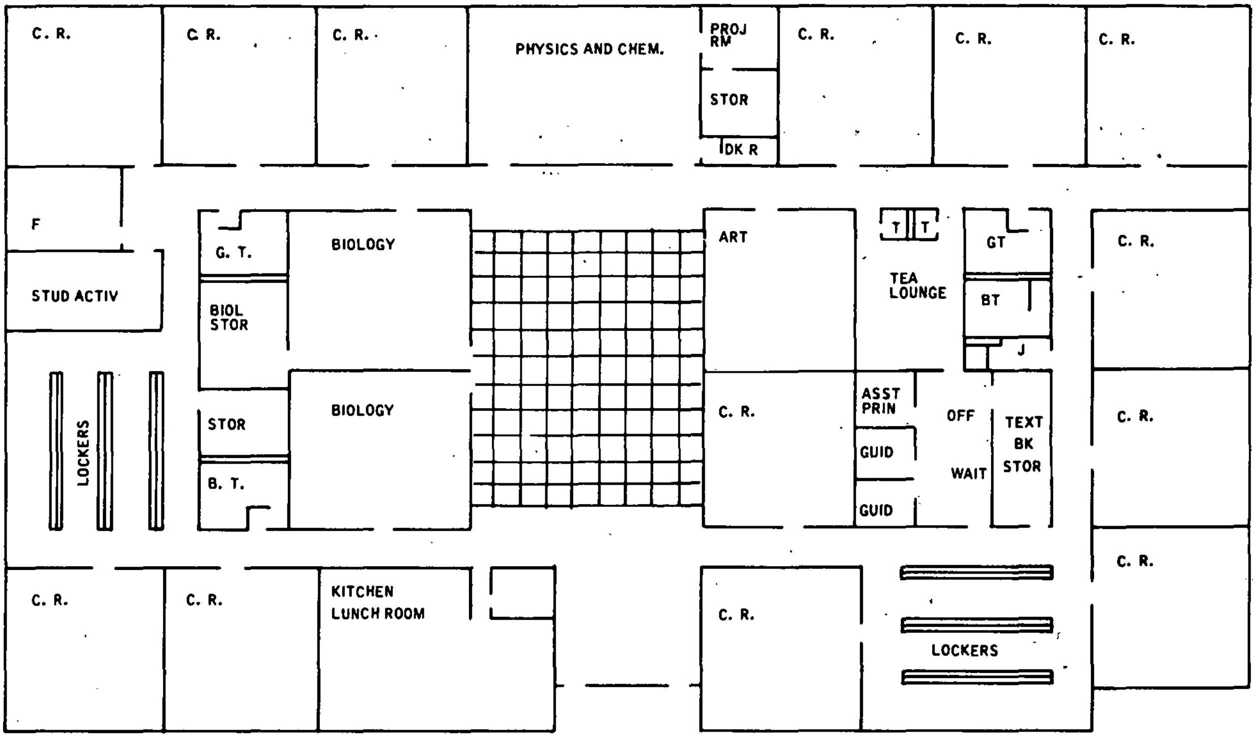
- New and Existing Construction Characteristics
- New and Existing Construction Thermal Resistance
- Floor Plan and Elevation
- People Load Schedule
- Lighting Load Schedule
- Appliance Load Schedule
- Ventilation Schedule
- Hot Water Use Schedule

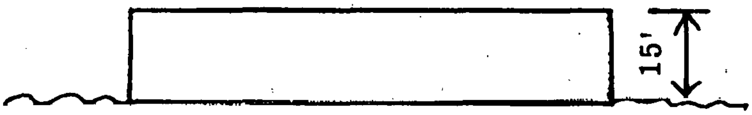
Table A-13. School Construction Characteristics

CHARACTERISTIC	EXISTING				NEW			
	NORTHEAST	NORTH CENTRAL	SOUTH	WEST	NORTHEAST	NORTH CENTRAL	SOUTH	WEST
Size - $(ft^2)/fl)$	38,750	39,750	39,750	39,750	39,750	39,750	39,750	39,750
Dimensions	265'x150'	265'x150'	265'x150'	265'x150'	265'x150'	265'x150'	265'x150'	265'x150'
No. of Floors	1	1	1	1	1	1	1	1
Height		15'	15'	15'	15'	15'	15'	15'
Foundation	4" concrete slab	4" concrete slab	4" concrete slab	4" concrete slab	4" concrete slab	4" concrete slab	4" concrete slab	4" concrete slab
Roof (Flat):	Built up	Built up	Built up	Built up	Built up	Built up	Built up	Built up
Deck	Metal	Metal	Metal	Metal	Metal	Metal	Metal	Metal
Insulation	none	none	none	none	2" rigid	2" rigid	2" rigid	2" rigid
Ext. Glass (ft^2)	1280	1280	1280	1280	1280	1280	1280	1280
Type	1/4" single	1/4" single	1/4" single	1/4" single	1" insulated	1" insulated	1" insulated	1" insulated
Ext. Doors (ft^2)	420	420	420	420	420	420	420	420
Type	1/4" glass	1/4" glass	1/4" glass	1/4" glass	1" insulated glass	1" insulated glass	1" insulated glass	1" insulated glass
Ext. Walls:	Metal curtainwall	Masonry	Metal curtainwall	Masonry	Metal curtainwall	Masonry	Metal curtainwall	Masonry
Insulation	none	none	none	none	2" rigid	1" rigid	2" rigid	1" rigid
Int. Finish	none	none	none	none	Gypbd.	Gypbd.	Gypbd.	Gypbd.
Area (ft^2)	9920	9920	9920	9920	9920	9920	9920	9920

Table A-14. School Construction Thermal Resistance

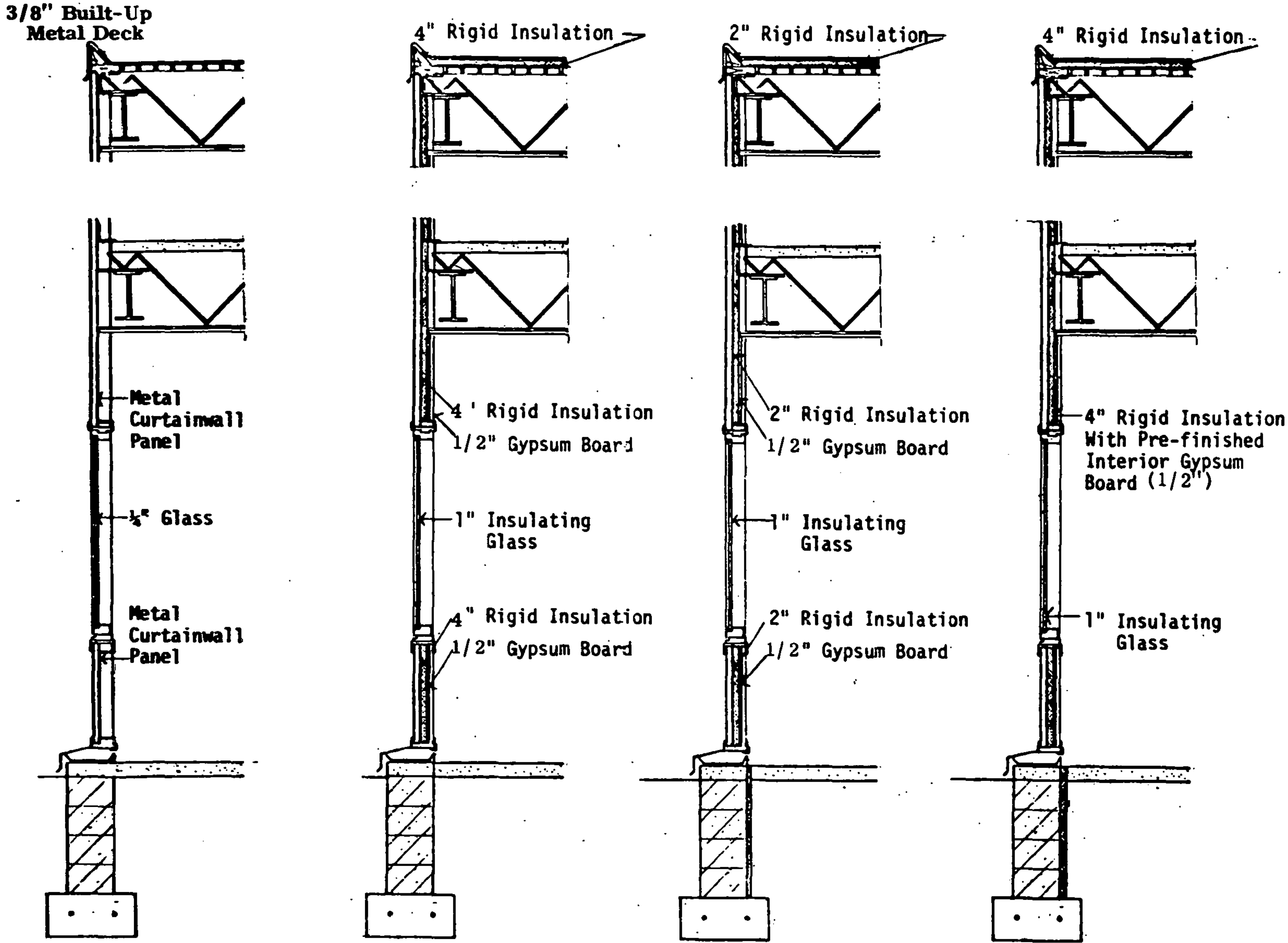
Surface	Region	Construction Description	R-Value
ROOF	N.E., N.C. S., W.	EXISTING:	
		3/8" Built-up Roof	0.33
		Metal Deck	0
		NEW:	
		3/8" Built-up Roof	0.33
		2" Roof Insulation	5.56
		Metal Deck	0
WALLS	N.E., S.	EXISTING:	
		2" Metal Curtainwall	2.00
		NEW:	
		2" Metal Curtainwall	2.00
		2" Rigid Insulation w/	8.00
		Prefinished Gypsum Board (1/2")	0.45
	N.C., W.	EXISTING:	
		4" Face Brick	0.44
		8" Conc. Block	2.00
		NEW:	
		4" Face Brick	0.44
		1" Rigid Insulation	4.00
		8" Concrete Block	2.00
		½" gypsum board	.45
GLASS * Windows/ Door	N.E., N.C. S., W.	EXISTING:	
		1/4" Single Light	.88
*R values include surface resistances		NEW:	
		1" Insulating Glass (Double - 1/2" air)	1.72
Basement Bottom Floor	N.E., N.C. S., W	4" Concrete Slab	.48





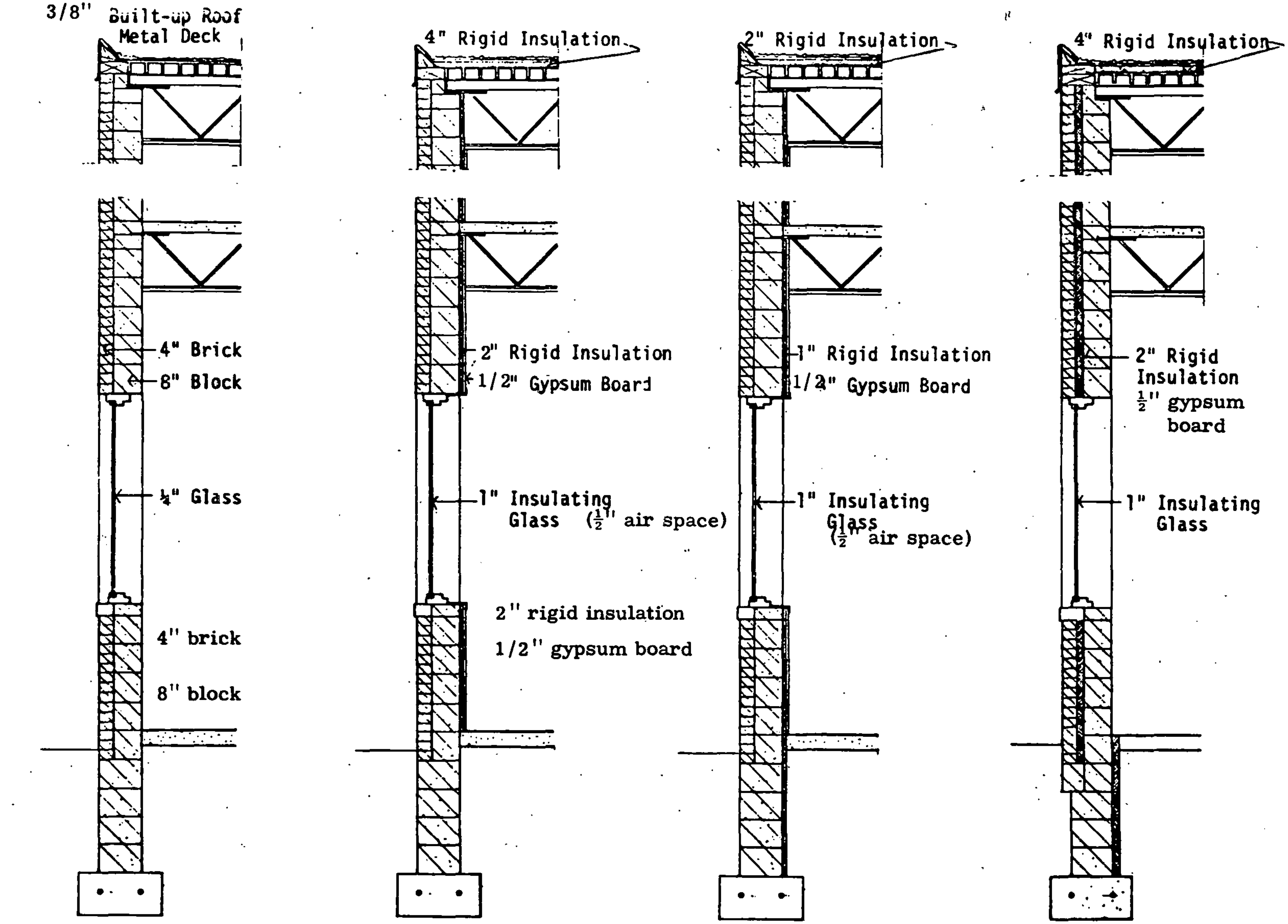
Elevation

Figure A-27. School Plan and Elevation



Existing-Base Case Existing-Improved New-Base Case New-Improved

Figure A-28. School Curtain Wall Construction (Northeast and South)



Existing-Base Case

Existing-Improved

New-Base Case

New-Improved

Figure A-29. School Masonry Construction (North Central and West)

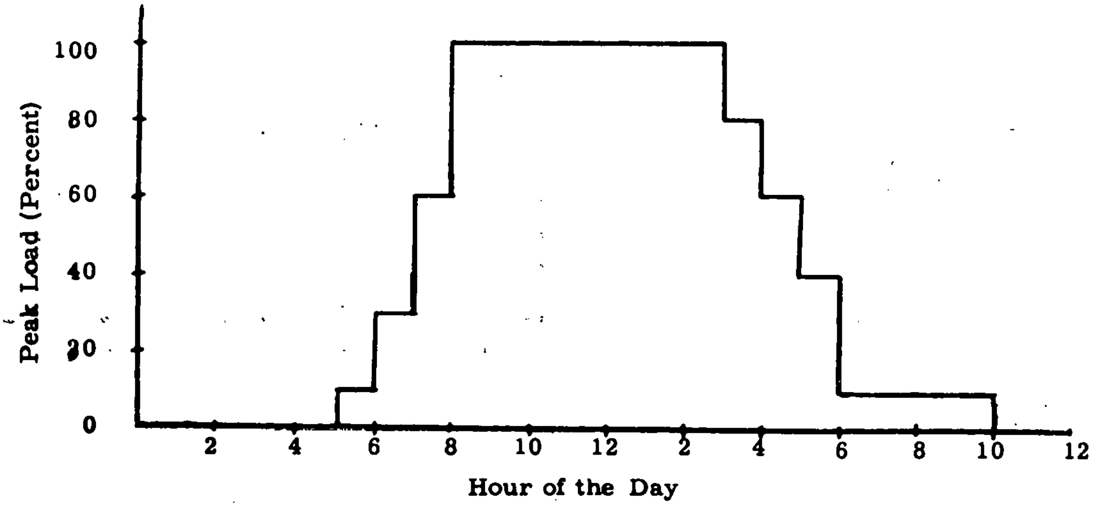


Figure A-30. School People Load Schedule

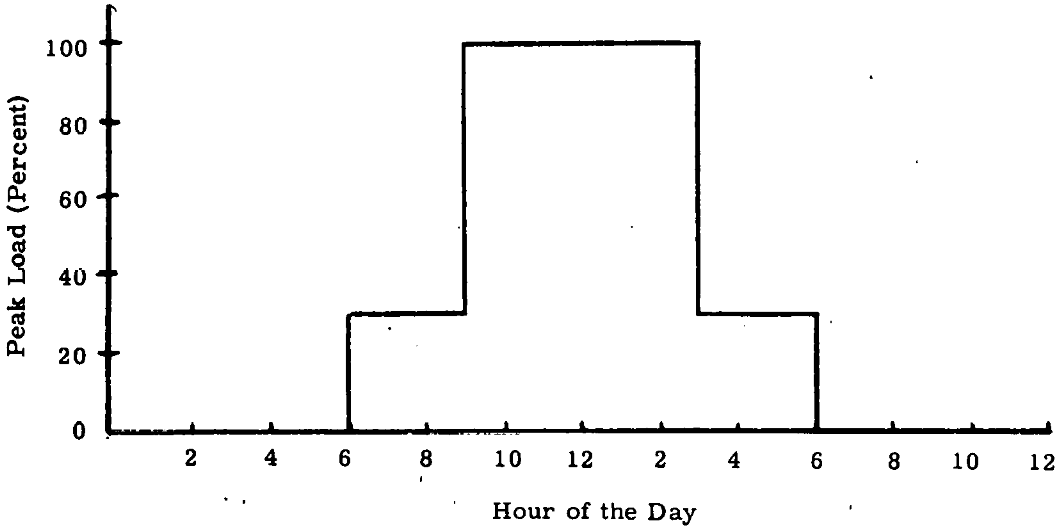


Figure A-31. School Lighting Schedule

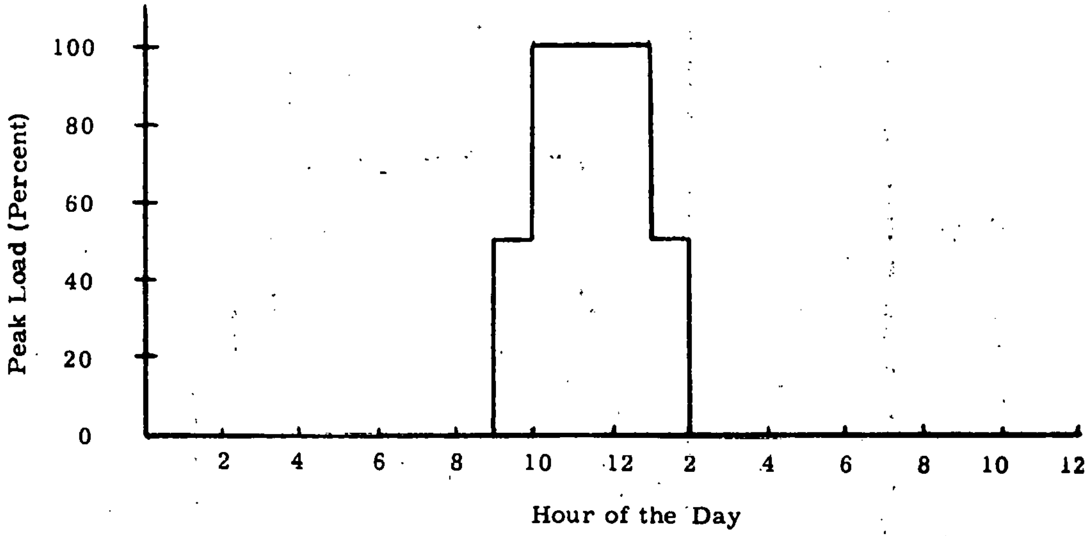


Figure A-32. School Appliance Load Schedule

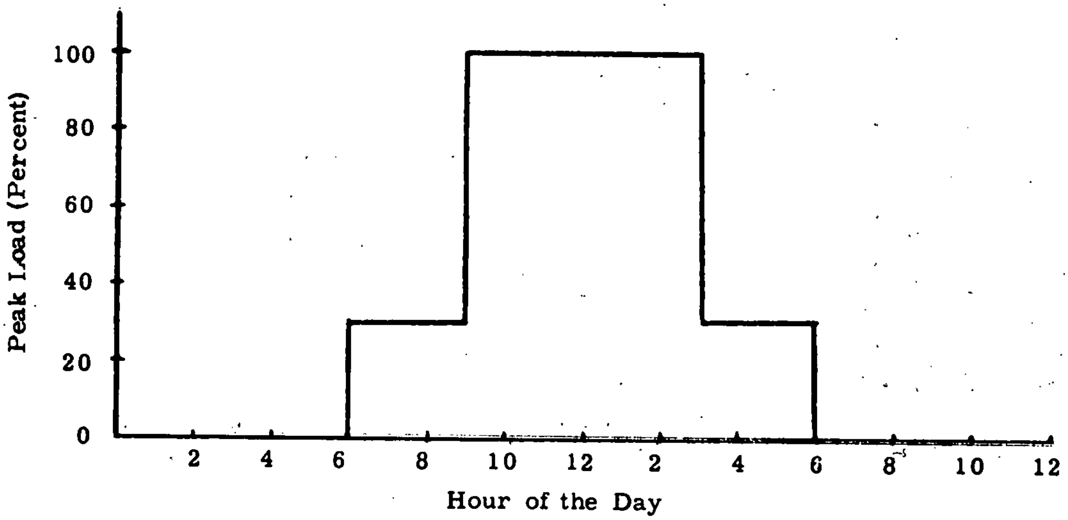


Figure A-33. School Ventilation Schedule

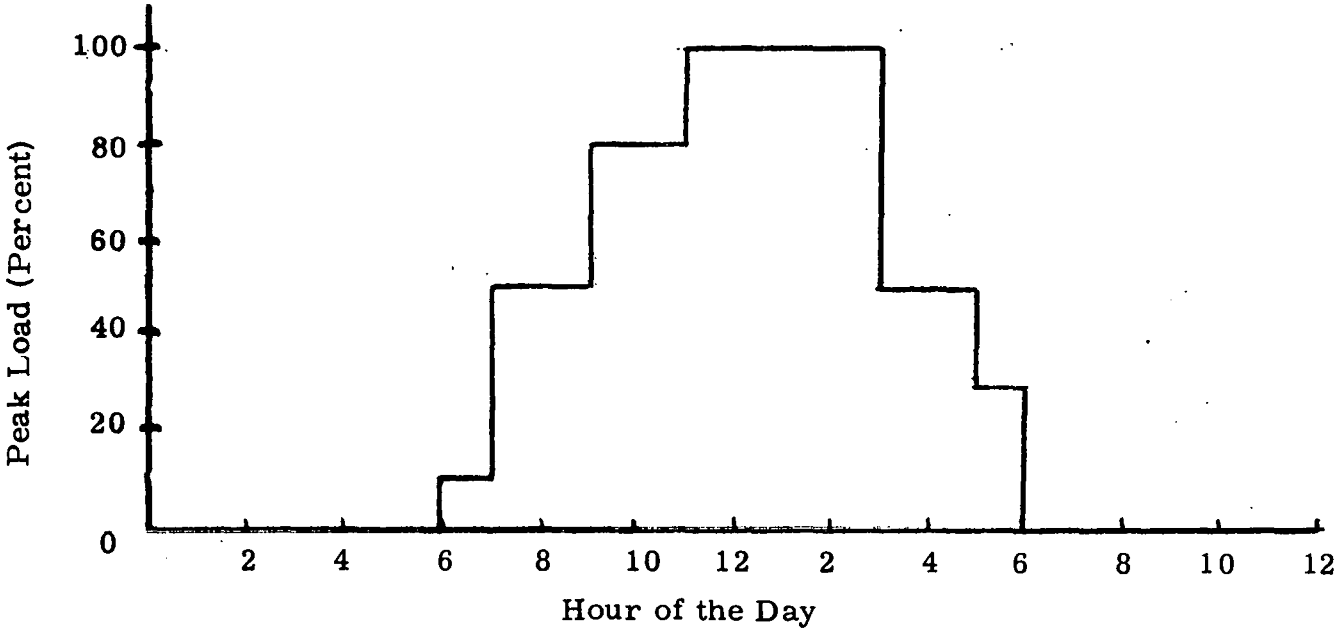


Figure A-34. School Hot Water Schedule

APPENDIX B
ALTERNATE ENERGY SOURCES AND ENERGY CONSERVATION TECHNIQUES
DESCRIPTION, COSTS

INTRODUCTION

This appendix describes the energy conservation techniques analyzed for each building type. Tables B-1 and B-2 describe alternate energy sources and energy conservation techniques surveyed during the study. These lists include all major energy conservation techniques. The techniques finally studied through simulation were selected from this list.

Table B-1. Alternative Energy Sources

1.0 PRIMARY ENERGY RESOURCES .

1.1 Conventional

- Fossil Fuels

  Coal
  Oil (from wells)
  Natural gas

- Non-Fossil Energy Sources

  Nuclear (light water reactor)
  Hydro-power
  Wood
  Well water
  Ground Water
  Outside air
  District steam
  District chilled water

1.2 Alternative or Unconventional

- Fossil Fuels

  Tar sands
  Oil shale
  Peat

- Nuclear

  Fast breeder reactor
  Fusion

- Solar Passive Systems

  Special windows
  Shutters
  Ponds

- Solar Active Systems

  - Thermal

    Flat Plate Collectors
    1 - liquid
    2 - air

    Concentrating Collector

    1 - central receiver
    2 - parabolic trough
    3 - slats
    4 - fresnel lens
    Shallow pond collector

  - Photovoltaic
    Terrestrial collectors
    Space station concept
  - Photochemical
  - Biological

- Wind (propeller-type windmill)

- Geothermal

- Tidal energy

- Wave energy

- Ocean Thermal

- Ocean Currents

- Biofuels
  - Crop residues (corn stalks, leaves, cobs, etc.)
  - Fuel crops (cattails)
  - Wood

- Waste Materials
  - Wood waste
  - Urban refuse (garbage)
  - Sewage sludge
  - Animal manures

2.0 SYNTHETIC CHEMICAL FUELS DERIVED FROM PRIMARY ENERGY RESOURCES

2.1 Low BTU gas (town gas, coal gas, water gas, manufactured gas, etc. approximately 50% H_2 and 50% CO, H. H. V. = 350 BTU/SCF).

- Coal, oil shale, or tar sands gasification

  1 - gasification plants
  2 - in situ gasification

- High temperature pyrolysis of wastes or crop residues.

2.2 High BTU gas (synthetic natural gas, essentially CH_4, H. H. V. = 1000 BTU/SCF).

- Methanation of low BTU gas
- Anaerobic digestion of animal manures or crop residues

2.3 Hydrogen

- Direct thermal decomposition of water using solar or nuclear reactor heat
- Electrolysis of water using electricity produced' from primary energy sources.
- Produced from low BTU gas by using the water gas shift reaction.
- Anaerobic digestion of animal manures or crop residues.
- Photochemical conversion.

2.4 Anhydrous ammonia produced from hydrogen.

2.5 Ethanol (ethyl alcohol or "grain alcohol").

- Fermentation of starchy biomass (directly) or glucose.
- Acid hydrolysis of cellulose

2.6 Methanol (methyl alcohol or "wood alcohol") by prolysis of cellulose.

2.7 Synthetic oil (carbonaceous liquids)

- In-plant conversion
  - Pyrolysis of wastes, crop residues, or coal
  - Hydrogenation of wastes, crop residues or coal.
  - Fischer-Tropsch synthesis using low BTU gas as the feedstock.
- In-situ conversion of coal, oil shale, or tar sands.

Table B-2. ENERGY CONSERVATION TECHNIQUES

1.0 BUILDING STRUCTURE AND ENVELOPE (ARCHITECTURAL DESIGN)

1.1 Alternative Energy Sources

- Solar
  - Windows
  - Awnings
  - Shutters
  - Deciduous trees
  - Blinds
  - Drapes
- Outside air
  - Natural ventilation
    - 1 - stack effect
    - 2 - wind
- Storage
  - High heat capacity walls and floors
  - Heat transfer media imbedded in walls and floors
  - Isothermal surfaces thru use of heat pipes
- Well water
- Ground water

1.2 Energy Conservation

1.2.1 Exterior Design Practice

- Use deciduous trees for their summer sun shading effects and wind break for buildings up to three stories.
- Use conifer trees for summer and winter sun shading and wind breaks.

- Cover exterior walls and/or roof with earth and planting to reduce heat transmission and solar gain.
- Shade walls and paved areas adjacent to building to reduce indoor/outdoor temperature differential.
- Use awnings to shade glass windows in summer.
- Reduce paved areas and use grass or other vegetation to reduce outdoor temperature building-up.
- Use ponds, water fountains, to reduce ambient outdoor air temperature around buildings.
- Locate building on-site to induce air flow effects for natural ventilation and cooling.
- Orient buildings to minimize wind effects on exterior surfaces.
- Select site with high air quality to enhance natural ventilation.
- Select a site that allows optimum orientation and configuration to minimize yearly energy consumption.
- Select site to reduce specular heat reflections from water.
- Utilize sloping site to partially bury building or use earth berms to reduce heat transmission and solar radiation.
- In climate zones where outdoor air conditions are close to desired indoor conditions for a major portion of the year, consider the following:
  - Adjust building orientation and configuration to take advantage of prevailing winds.
  - Use operable windows to control ingress and egress of air through the building.

- Adjust the configuration of the building to allow natural cross ventilation through occupied spaces.
- Utilize stack effect in vertical shafts, stairwells, etc., to promote natural air flow through the building.

1.2.2 Structure and Interior Design Practices

Windows

- Use minimum ratio of window area to wall area.
- Use double glazing.
- Use triple glazing.
- Use double reflective glazing.
- Manipulate east and west walls so that windows face south.
- Use window frames that form a thermal bridge.
- Allow direct sun on windows November through March.
- Use operable thermal shutters which decrease the composite "U" value to 0.1.
- Use storm sash or high efficiency glass.
- Shade windows from direct sun April through October.
- Increase window size but do not exceed the point where yearly energy consumption, due to heat gains and losses, exceeds the savings made by using natural light.
- Use permanently sealed windows to reduce infiltration in climatic zones where this is a large energy user.
- Where codes or regulations require operable windows and infiltration is undesirable use windows that close against a sealing gasket.

Walls, Ceilings and Floors

- Consider the use of the insulation type which can be most efficiently applied to optimize the thermal resistance of the wall or roof; for example, some types of insulation are difficult to install without voids or shrinkage.
- Protect insulation from moisture originating outdoors, since volume decreases when wet.
- Use insulation with low water absorption and one which dries out quickly and regains its original thermal performance after being wet.
- Where sloping roofs are used, face them to the south for greatest heat gain benefit in the winter time.

Building Arrangements

- Group service rooms as a buffer and locate at the north wall to reduce heat loss or the south wall to reduce heat gain, which ever is the greatest yearly energy user.
- Use corridors as heat transfer buffers and locate against external walls.
- Locate rooms with high process heat gain (computer rooms) against outside surfaces that have the highest exposure loss.
- Use landscaped open planning which allows excess heat from interior spaces to transfer to perimeter spaces which have a heat loss.
- Group rooms in such a manner that the same ventilating air can be used more than once, by operating in cascade through spaces in decreasing order by priority, i.e., office-corridor-toilet.

- Use high ceilings to promote stratification in rooms with high internal heat source.
- Reduce ceiling heights to reduce the exposed surface area and the enclosed volume.
- Increase the density of occupants (less gross floor area per person) to reduce the overall size of the building and yearly energy consumption per capita.
- Spaces for similar functions located adjacent to each other on the same floor reduce the use of elevators.
- Use elevators rather than escalators for vertical travel.
- For high traffic densities through one or two floors, use staircases or ramps rather than escalators.
- Reduce the number of elevators installed by scheduling their use for essential purposes only (for example, stops at every other floor would eliminate single floor trips and enforce use of staircases).

Detail Considerations

- Minimize requirements for snow melting to those that are absolutely necessary and, where possible, utilize waste heat for this service.
- For hot water piping and storage tanks, if used, increase the amount of insulation or select one with better "R" value.
- When storage tanks are used, locate them as close to the point of usage as possible.
- Plug air leaks around penetrations.
- Seal all cracks.

- Use vestibules and revolving doors as buffer between outside environment and interior.

2.0 Building Systems

2.1 Heating, Ventilating and Air Conditioning Plant

2.1.1 Alternative Energy Sources

- Electricity
- Oil
- Gas
- Outside Air
- Ground Water
- Well Water
- Heat Recovery System (exhaust air preheats incoming outdoor air)

  Heat Pipe
  Air to Air
  Glycol Loop
  Install on-site waste heat recovery incinerators for disposal of solid wastes. The waste heat can be used for space heating, ventilation, water absorption, refrigeration or other thermal uses.
- Coal
- Wood
- Peat
- Wind
- Energy Storage

  Mechanical

Flywheels
Compressed air
Thermal (either "hot" or "cold" storage)
Water (or ice)
Rocks (pebble bed)
Molten salts
Chemical
Batteries
Regenerative fuel cells

- Solar Heating

  Space heating
  Heat pump Booster

- Solar Cooling

  Absorption refrigeration
  Rankine system

2.1.2 Energy Conservation Systems

- Air Economizer System

  Use outdoor air for sensible cooling whenever conditions permit and when re-captured heat cannot be stored.

  Use adiabatic sturation to reduce temperature of hot, dry air to extend the period of time when "free cooling" can be used.

  In the summer when the outdoor air temperature at night is lower than indoor temperature, use full outdoor air ventilation to remove excess heat and pre-cool structure.

- Heat Pump (either electrically driven or driven by on-site prime mover with waste heat recovery or wind driven).

- Outdoor air source
- Water source
- Ground water
- Surface Water
- Sewer
- Solar Source
- Internal Source
- Use heat pumps in place of electrical resistance heating.
- Use unitary water/air heat pumps that transport heat energy from zone to zone via a common hydronic loop.
- Use thermal storage in combination with unit heat pumps and a hydronic loop so that excess heat during the day can be captured and stored for use at night.
- Improved heat pump COP

    200 percent oversized on cooling with 2speed compressor
    Bigger coils
    Higher efficiency motors
    Use heat pumps both water/air and air/air if a continuing source of low-grade heat exists near the building, such as a lake, river, etc.

- Total energy system (the prime mover also drives a heat pump, if necessary, to supply additional heat).

    Piston engine
    Gas turbine

        steam or organic fluid rankine bottoming cycle
        absorption refrigeration using gas turbine exhaust directly, or heat rejected by bottoming cycle.

Fuel Cells

absorption refrigeration with waste heat
organic fluid rankine bottoming cycle using waste heat

Use a total energy system if the life cycle costs are favorable.

Where steam is available, use turbine drive for large items of equipment.

Improving Efficiency and Utilization

- Use electric ignition in place of gas pilots for gas burners.
- Use spot heating and/or cooling in spaces having large volume and low occupancy.
- Air cleaners and scrubbers for complete air recirculation.
- Extract waste heat from boiler flue gas by extending surface coils or heat pipes.
- Use liquid-cooled transformers and captive waste heat for beneficial use in other systems.
- In canteen kitchens, use gas for cooking rather than electricity.
- Use conventional ovens rather than self-cleaning type.
- Utilize a sloping site to accommodate entrances of multi-levels to reduce elevator mileage.
- Use solid state controls for elevators.
- Separate and salvage usable materials which have a commercial value.
- Re-cycling many materials consumes less raw source energy than producing virgin materials and could have economic benefit as well.

- Consider operating chillers in series to increase efficiency.
- Turn off pilots in gas furnaces.
- Use chilled water storage systems to allow chillers to operate at night when condensing temperatures are lowest.
- Use modular boilers for heating and select units so that each module operates at optimum efficiency.
- Reduce hot water generating and storage temperature to the minimum required for hand washing (to 120°).
- Match motor sizes to equipment shaft power requirements and select to operate at the most efficient point.
- Maintain power factor as close to unity as possible.
- Reduce length of cable runs.
- Increase conductor size within limits indicated by life cycle costing.
- Use high voltage distribution within the building.
- Match characteristics of electric motors to the characteristics of the driven machine.
- Design and select machinery to start in an unloaded condition to reduce starting torque requirements. (For example, start pumps against closed valves.)
- Use direct drive whenever possible to eliminate drive train losses.
- Use high efficiency transformers (these are good candidates for life cycle costing).

Improved HVAC Design Practice

- Don't use resistance heat
- Don't use new energy for reheat
- Insulation
  - hot water pipes
  - ducts in exposed areas
- Don't overdesign fan system
- Don't overdesign chiller size
- Don't overdesign furnace size
- Wet cooling towers instead of dry heat exchangers.
- Don't take in excessive outdoor air unless it will cool the building.
- Use of high efficiency air cleaners (electronic)
- Don't warm up (insulate) water going to water coolers.
- Don't use air doors
- Don't use excessive glass
- Improved efficiency air conditioners
- Improved efficiency furnaces.
- Improved efficiency heat pumps.
- Shower heads that use less water.
- In principle, select the air handling system which operates at the lowest possible air velocity and static pressure.

- Design air handling systems to circulate sufficient air to enable cooling loads to be met by a 60°F air supply temperature and heating loads to be met by a 90°F air temperature.
- Design HVAC systems so that the maximum possible proportion of heat gain to a space can be treated as an equipment load, not as room load.
- Schedule air delivery so that exhaust from primary spaces (offices) can be used to heat or cool secondary spaces (corridors).
- Design duct systems for low pressure loss.
- Use high efficiency fans.
- Use low pressure loss filters concomitant with contaminant removeable.
- Use one common air coil for both heating and cooling.
- Reduce or eliminate air leakage from duck work.
- Limit the use of re-heat to a maximum of 10 percent gross floor area and then only consider its use for areas that have a typical fluctuating internal loads such as conference rooms.
- Design chilled water systems to operate with as high a supply temperature as possible -- suggested goal -- 50° (this allows higher suction temperatures at the chiller with increased operating efficiency).
- Use modular pumps to give varying flows that can match varying loads.
- Exhaust air from center zone through the lighting fixtures and use this warmed exhaust air to heat perimeter zones.

- Design HVAC systems so that they do not heat and cool air simultaneously.
- Select high efficiency pumps that match load. Do not oversize.
- Design piping systems for low pressure loss and select routes and locate equipment to give shortest pipe runs.
- Adopt as large a temperature differential as possible for chilled water systems and not water heating systems.
- Provide all outside air dampers with accurate position indicators and insure dampers are airtight when closed.
- Locate cooling towers or evaporate coolers so that induced air movement can be used to provide or supplement garage exhaust ventilation.
- Avoid the use of straight electric heating for hot water, consider instead using a heat pump.

2.2 Lights

2.2.1 Alternative energy sources

- Natural lighting

2.2.2 Energy Conservation

- Turn off unused lights
- Delamp
- Use task lighting
- Replace incandescent bulbs with high efficiency lights.

3.0 Domestic Water

3.1 Alternative Energy Sources

- Meeting hot water heating needs from the following sources:
    - Rejected heat of compression from refrigeration units (both air conditioning and kitchen freezers and cold rooms).
    - Hot condensate return from steam operated systems.
    - Rejected heat from diesel or gas engines.
    - Waste heat from drains used in conjunction with heat pumps.
    - Waste heat from transformers.
- Collect rain water for use in building.
- Where fresh water is in short supply, consider the use of solar stills.
- Recycle waste water for toilet flushing.

3.2 Energy Conservation

- Boost hot water temperature locally for kitchens, etc., rather than provide higher temperatures for entire building.
- Extract cooling from cold water supply
- Lower hot water temperature
- If boilers are used as primary heat source for domestic hot water, install a boiler to match the load rather than use an oversized heating boiler all summer. (Careful selection of modular heating boiler sizes could achieve the same end).

- Use gravity circulation for domestic hot water rather than pumps.
- Arrange circulating pipework to minimize length of dead legs connecting to faucets (this saves water as well as energy as it eliminates the need to draw off quantities of cold water before hot water can be obtained.)
- To reduce the quantity of hot and cold water used:
  - Select kitchen equipment such as dishwashers that have minimum water requirements.
  - Use a single system to meet handwashing needs in toilets.
  - Use spray type faucets with flow restrictions.
  - Use self-closing valves to control faucets.
  - Use well water, if available.
  - Use waterless or low volume flush water closets.
  - Select a water treatment system for cooling towers that allows high cycles of concentration (suggested target greater than 10:7) and reduces blowdown quantity.
  - Schedule boiler blow down on air "as needed" basis rather than a fixed timetable.
  - Use restricted flow showerhead (2.5 gal/min. maximum flow).

3.0 Control System

3.1 Alternative Energy Sources

Develop control schemes to optimize use of alternative sources.

3.2 Energy Conservation

- Computer Based Control Systems
- Monitoring
- Fire-life safety
- Optimize control of energy consuming process
- Schedule maintenance
- Control Strategies
    - Night setback (lower or raising stat setpoints)
    - Fan shutdown
    - Load Management
        - duty cycling
        - peak shedding
        - thermal storage during off peak times
- Provide control to automatically shut off recirculating pumps during weekends, nights and periods of the day which are well-defined, when hot water usage is light.
- Heat building to no more than 60°F when unoccupied.
- Cool building to no less than 78°F when occupied.
- Do not cool building when it is unoccupied.
- Schedule morning start up in winter so that the building is at 63°F when occupants arrive and warms up to 68°F over the first hour.

- Limit pre-cooling to start-up in morning to give building temperature of 5°F less than outdoor temperature or 80°F, whichever is highest.
- Close outdoor air dampers for the first hour of occupancy whenever outdoor air has to be either heated or cooled.
- Close outdoor air dampers for the last hour of occupation whenever outdoor air has to be either heated or cooled.
- Turn off heating or cooling 30 minutes before the end of the occupied period.
- Close outdoor air dampers for 10 minutes in every hour (adjust time period according to experience.)
- Allow humidity to vary naturally in the building between 20 percent RH and 65 percent RH. Only add or remove moisture when building conditions exceed those limits.

ENERGY CONSERVATION TECHNIQUES

This discussion covers how each energy conservation technique works and how much it costs to buy and install for all selected techniques for each building type.

Single Family Residence

Energy conservation techniques analyzed for both new and existing single family residences include:

- Night Setback
- Air Economizer
- Increased Domestic Water Tank Insulation and Decreased Temperature
- Reflective Films on Glass
- Awnings
- High Efficiency Lighting
- Insulation
- High Furnace Efficiency

Night Setback

Description/Assumptions -- Night setback consists of automatically setting back the thermostat during the heating season. In the simulations for a single family residence, the heating setpoint was 68°F. Night setback assumes a heating setpoint of 63°F between the hours of 10:00 pm and 6:00 am.

Costs -- For cost purposes, the Honeywell Chronotherm was selected as representative of this type of device. The retail price is 55.00 and is assumed to be the same for all regions.

New Single Family Residence -- Installed costs for a new single family residence are based on installation during initial construction. Installed costs* are:

City	Material	Labor	Total
Omaha	$ 55.00	$21.36	$76.36
New York	55.00	27.98	82.98
Atlanta	55.00	20.72	75.72
Albuquerque	55.00	17.94	72.94

Existing Single Family Residence

For existing single family residences, extra time would be required to route wires through areas of limited accessibility. To account for this difference, the installation portion of the costs were doubled. Installed costs for existing single family residences are:

City	Material	Labor	Total
Omaha	$55.00	$ 42.72	$ 97.72
New York	55.00	55.96	110.96
Atlanta	55.00	41.44	96.44
Albuquerque	55.00	35.88	90.88

*Installation costs are based on labor times and rates for controls and instrumentation as specified in the 1976 Dodge Manual for Building Construction Pricing and Scheduling.

Air Economizer

Description/Assumptions -- The air economizer is a method of controlling the introduction of outdoor air into a conditioned space to provide maximum operating economy during the cooling cycle. Whenever the temperature and relative humidity of the outdoor air are within prescribed limits and the thermostat is calling for cooling, the economizer will introduce outdoor air and distribute it through the building instead of turning on the compressor.

Figure B-1 illustrates the operational sequence of an air economizer system. A two-stage cooling thermostat provides sequential operation of the economizer cycle and mechanical cooling equipment. The air economizer operates through the first stage. The mechanical cooling equipment is controlled by the second stage. An enthalpy controller senses outdoor air conditions. If the outdoor air enthalpy is below the set point, the outdoor exhaust and outdoor supply are opened and return dampers are closed. The furnace fan pulls in cool dry outdoor air and blows it through the supply ducts into the controlled space. Warm return air is exhausted outdoors via the exhaust air outlet. If the temperature of the space continues to rise, the second stage turns on the compressor. During compressor operation, the outdoor air economizer cycle continues to ensure that the compressor operates under minimum load. Warm air from the space is exhausted rather than recirculated.

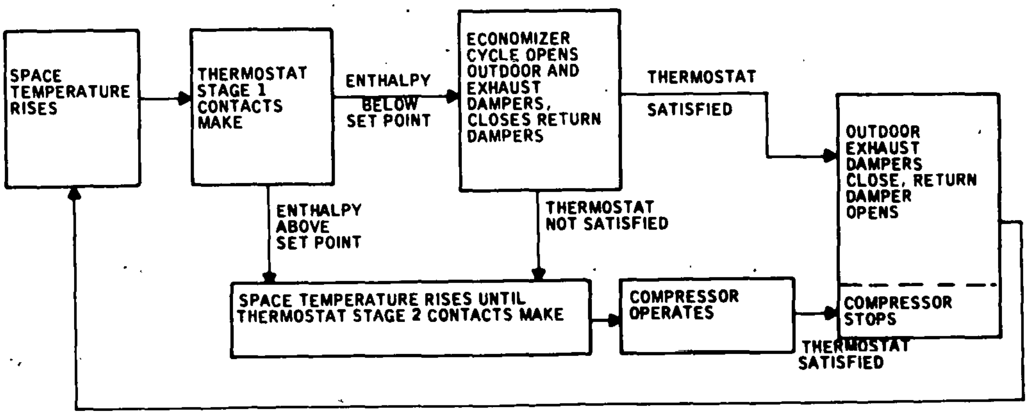


Figure B-1 Operational Sequence of an Air Economizer/Cooling System

If the enthalpy of the outdoor air is above the dial setting, the economizer will not operate on a call for cooling. In this case, all cooling is provided by the mechanical cooling equipment.

Costs -- Installed costs of an air economizer system within a single family residence are highly dependent on the type of heating/cooling system, layout and ducting and type of structure. Figures B-2 and B-3 illustrate typical installations for warm air furnaces in basement and ground floor closet installations. Costs[1] developed are based on these typical installations.

Installation of an air economizer system requires the following components:

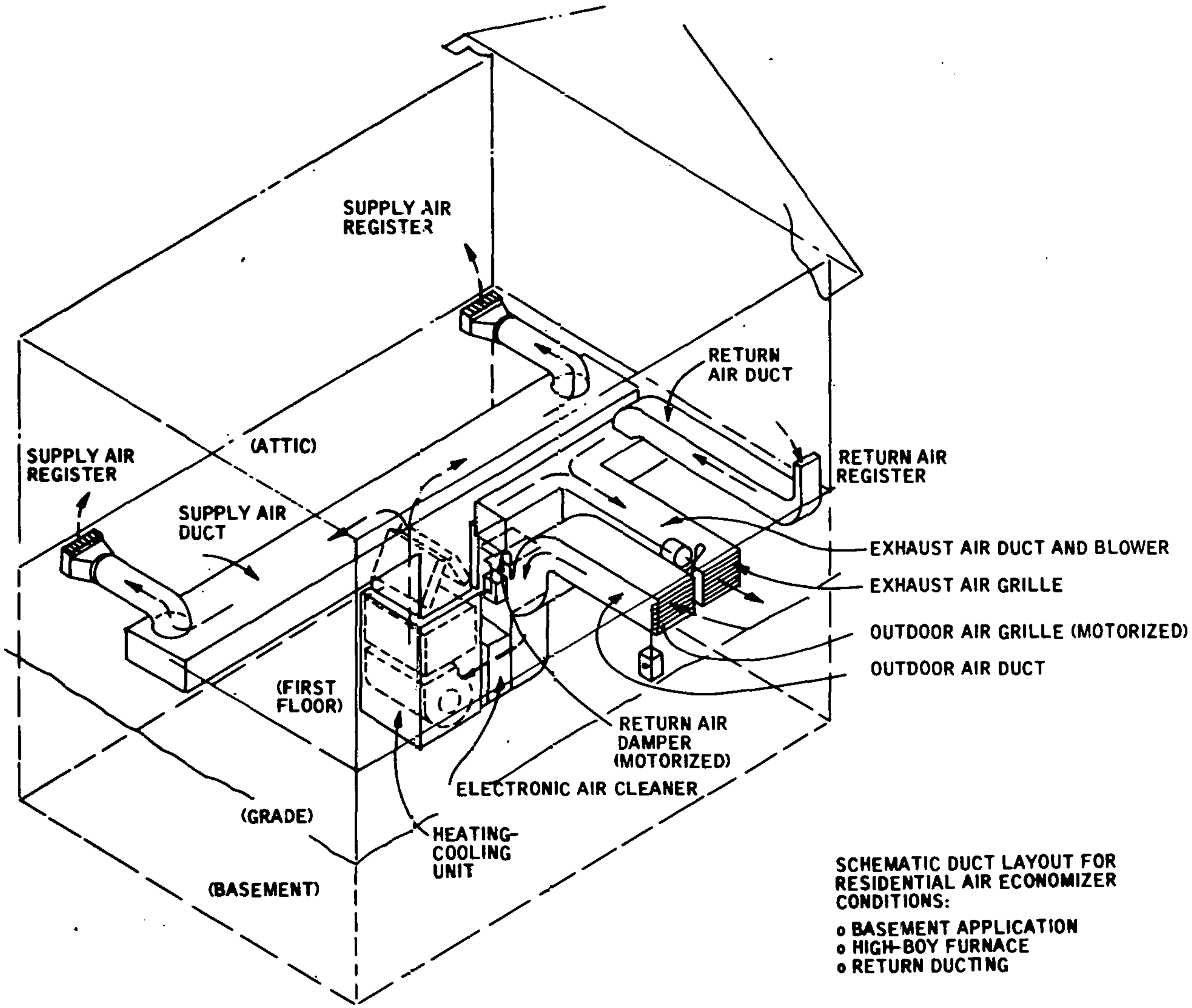
- Two-stage Cooling Thermostat
- Enthalpy Controller
- Exhaust Fan
- Damper Motor and Linkage
- Dampers
- Additional Ducting

New Single Family Residence -- Installation costs of an air economizer within a new single family residence in the four cities is[2]:

References:

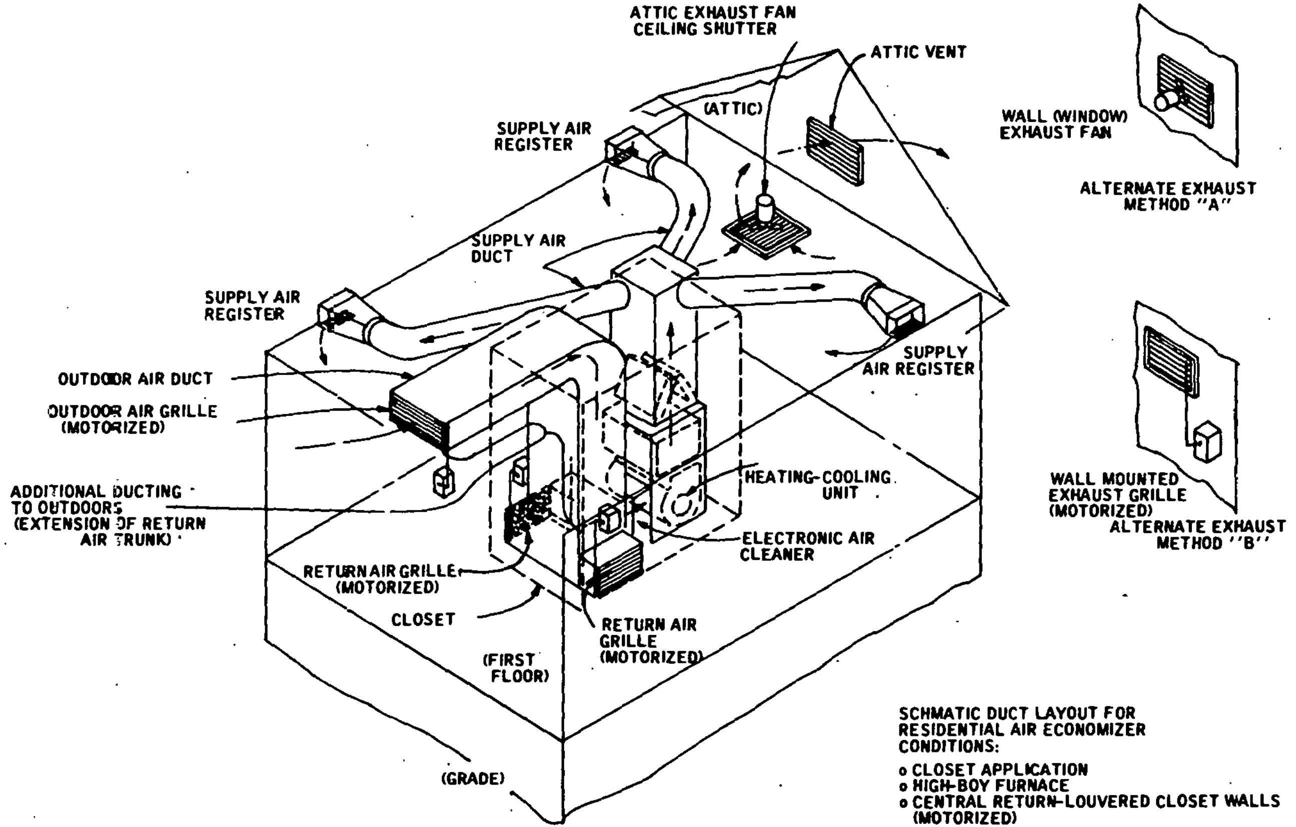
1 - Residential Air Economizer, Sales and Installation Guide, Honeywell, 1976.

2 - Installation costs are based on labor times and rates for heating system components as specified in the 1976 Dodge Manual for Building Construction Pricing and Scheduling.



SCHEMATIC DUCT LAYOUT FOR RESIDENTIAL AIR ECONOMIZER CONDITIONS:
- o BASEMENT APPLICATION
- o HIGH-BOY FURNACE
- o RETURN DUCTING

Figure B-2 TYPICAL BASEMENT INSTALLATION



SCHMATIC DUCT LAYOUT FOR
RESIDENTIAL AIR ECONOMIZER
CONDITIONS:

- CLOSET APPLICATION
- HIGH-BOY FURNACE
- CENTRAL RETURN-LOUVERED CLOSET WALLS (MOTORIZED)
- CONTROLLED AIR INTAKE

Figure B-3 TYPICAL CLOSET INSTALLATION

	Labor			
City	Elec	Sheet Metal	Mat	Total
Omaha	$ 74	$ 56	$ 310	$ 440
Atlanta	71	50	310	431
Albuquerque	62	56	310	428
New York	96	83	310	489

Existing Single Family Residence -- Installation in an existing building would require additional labor for wiring and ductwork. Installed costs are:

	Labor[2]			
City	Elec	Sheet Metal	Mat[1]	Total
Omaha	$ 95	$ 74	$ 310	$ 479
Atlanta	92	66	310	468
Albuquerque	80	75	310	465
New York	125	110	310	545

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[1] - Ibid, page

[2] - Ibid, page

Increased Domestic Hot Water Tank Insulation/Reduced Temperature

Descriptions/Assumptions--

Energy conservation applied to domestic hot water tanks that are considered in the mixed strategies analysis include increased insulation and reduced water temperature.

A recent study[3] indicates that domestic hot water tanks are typically insulated with 1 inch of mineral wool or fiberglass for fossil fuel types and 2 inches for electric types. Their results indicate that increasing the insulation can achieve a fuel reduction of 21.6% for fossil fuel types and 5.6% for electric water heaters.

The energy conservation technique selected for analysis consisted of increasing the tank insulation by R-6 and decreasing the temperature from 140°F to 130°F.

Costs are based on a commercially available product consisting of approximately 1 inch of insulation clad in a vinyl jacket. Although this product can be installed by the homeowner, nominal installation costs are included:

City	Labor	Material	Total
Omaha	$10.00	$19.95	$ 29.95
Atlanta	8.20	19.95	28.15
Albuquerque	7.90	19.95	27.85
New York	12.10	19.95	32.05

[3] James J. Mutch, Residential Water Heating: Fuel Conservation, Economics, and Public Policy Prepared for the National Science Foundation by Rand Corporation, May 1974, R-1498-NSF.

Reflective Films on Glass

Description/Assumptions--

Reflective films consist of a thin polyester film with a transparent aluminum coating on one side. When applied to the inside of a window, it reduces both the shading coefficient and heat transfer coefficient of the glass.

Percent reductions of shading and heat transfer coefficients are dependent on the particular brand of reflective film. Reductions of 75 and 20 percent for shading and heat transfer coefficients, respectively, were selected as representative of available reflective films.

Costs-- for New and Existing Single Family Residences

Installed costs of reflective films on new and existing single family residences in the four cities are:

City	Labor	Material	Total
Omaha	\$ 1.00	\$ 1.00	\$ 2.00/ft^2
Atlanta	.82	1.00	1.82/ft^2
Albuquerque	.79	1.00	1.79/ft^2
New York	1.21	1.00	2.21/ft^2

Insulation

Description/Assumptions--

The insulation packages evaluated for the single family dwelling involve various combinations of changes in window types, changes in wall composition and additions to amounts of insulation in the ceiling. For the new house, all insulation packages include replacing the single pane windows with double pane insulated glass windows and installing up to 12" of batt insulation in the ceiling. Also, if sheet insulation is added on a new house, the normal plywood exterior sheathing is not used. For the existing house, all the insulation packages include the addition of storm windows.

The effect of the insulation packages is to increase thermal resistance of the structure's skin and decrease the infiltration rate by making the structure's skin less porous. The base case infiltration rates are .75 air change per hour for the new house and one air change per hour for the existing house.

Costs--

Costs for the new structure modifications are listed in Table B-3 and are the extra costs involved to build the house as modified by the ECT's as compared to building the base house described in Appendix A. Costs for modifications to the existing structure are listed in Table B-4. These are the costs involved for having a contractor furnish the materials and do the work.

TABLE B-3. INSULATION COSTS FOR NEW SINGLE FAMILY DWELLINGS

Case No.	Additions/Alterations	Infiltration (Air Change Per Hour)	Cost in Omaha	Cost in New York	Cost in Albuquerque	Cost in Atlanta
1	Walls - 2" Styrofoam Sheets	0.45	$855	$765	$1235	$915
2	Walls - 2x6 Studs - 6" Batt Insulation	0.50	$944	$946	$966	$981
3	Walls - 1" Stryofoam - 2x6 Studs - 6" Batt Insulation	0.45	$958	$903	$978	$1002
4	Walls - As in 3 Windows - Add Storms	0.375	N/A	N/A	$1378	$1206
5	Walls - 2" Styrofoam - 2x6 Studs - 6" Batt Insulation Add Storm Windows	0.375	$1180	$1135	$1935	$1456

TABLE B-4. INSULATION PACKAGE COSTS FOR EXISTING SINGLE FAMILY DWELLING

Case No.	Additions/Alterations	Infiltration (Air Change Per Hour)	Cost in Omaha	Cost in New York	Cost in Albuquerque	Cost in Atlanta
1	Storm Windows	0.95	$368	$438	$367	$374
2	12" Loose Fill in Ceiling Storm Windows	0.90	$675	$755	$728	$756
3	12" Loose Fill in Ceiling 3.5" Foam in Walls Insulated Glass and Storms	0.75	$1532	$1682	$1518	$1591
4	12" Loose Fill in Ceiling 3.5" Foam in Walls Insulated Glass and Storms Caulk and Weatherstrip	0.5	$2025	$1925	$1827	$1796
5	14" Loose Fill in Ceiling 3.5" Foam in Walls Insulated Glass and Storms	0.72	$1593	$1745	$1562	$1637

High Efficiency Lights

Description/Assumptions--

High efficiency lighting can be achieved by replacing or initially installing flourescent lighting fixtures in lieu of incandescent fixtures while holding the level of lighting (Lumens) at the same level. This analysis assumes 80 percent of the lights are replaced with flourescents.

Costs--

Flourescent fixtures are more expensive than comparable incandescent fixtures. Assuming reasonable fixtures within the rooms, the following cost differences were obtained (Wards 1976 catalog) for new and existing residences.

New Single Family Residence--

Room	Incandescent	Flourescent	Added Cost
Bath	$ 16.00	$ 28.00	$ 12.00
Bedrooms	114.00	180.00	66.00
Kitchen	18.00	32.00	14.00
Living Room	200.00	270.00	70.00
Totals			162.00

It is assumed that flourescent lights are installed during initial construction. No additional installation costs are added. Costs were assumed to be identical for all four regions.

Existing Single Family Residence--

For existing residences, it is assumed that 80 percent of the fixtures are also replaced by flourescent lights. Cost of fixtures for each room include:

Room	Flourescent Fixtures
Bath	28.00
Bedrooms	120.00
Kitchen	32.00
Living Room	210.00
Total	390.00

Installed costs for each city for existing residences were obtained using rate structures for electricians:

City	Labor	Material	Total
Omaha	$ 171.41	$390.00	$ 561.41
New York	220.55	390.00	610.55
Atlanta	178.82	390.00	568.82
Albuquerque	157.95	390.00	547.95

Awnings

Description/Assumptions--

Awnings are a common energy conservation technique for shading windows during the cooling season. The awnings considered for this analysis are of the metal rool up type; down during the cooling season and up during the heating season. Awnings were considered on three sides of the building; east, south and west.

Costs for New and Existing Single Family Residences --
Installed costs for both new and existing single family residences (per awning) are:

City	Labor	Material	Total
Omaha	$7.50	$ 42.95	$ 50, 45
Atlanta	6.83	42.95	49.78
Albuquerque	6.75	42.95	49.70
New York	8.33	42.95	51.28

Total installed costs for the single family residence are:

City	Total
Omaha	$ 554.95
Atlanta	547.58
Albuquerque	546.70
New York	564.08

Furnace Efficiency

The high efficiency furnace assumes that the furnace efficiency is increased from 55 percent to 80 percent.

Costs--

New Single Family Residence--

It was assumed that the high efficiency furnace was installed in the new building at the time of construction. No additional instalation costs were assumed.

City	Material	Total
Omaha	$ 150	$ 150
Atlanta	150	150
New York	150	150
Albuquerque	150	150

Existing Single Family Residence --

	Labor			
City	Pipefitter	Sheet Metal	Material	Total
Omaha	$ 123.	$ 128.	$ 450	$ 701
Atlanta	104.	114.	450	668
New York	136.	191.	450	777
Albuquerque	117.2	130.	450	697

Multi-Family Residence

Energy conservation techniques analyzed for both new and existing multi-family residences include:

- Night Setback
- Air Economizer
- Increased Domestic Water Tank Insulation and Decreased Temperature
- Reflective Films on Glass
- Awnings
- High Efficiency Lighting
- Insulation
- High Efficiency Furnace

Night Setback

Description/Assumptions--

The night setback device, operational hours and setpoints are identical to those described for the single family residence. The multi-family building assumes that each apartment has its own night setback device.

Costs--

Installed costs for the multi-family building are assumed identical to those described for the single family residence. Since each apartment has its own device, costs are multiplied by eleven (number of occupied apartments.)

New Multi-Family Residence--

City	Material	Labor	Total
Omaha	$ 605.00	$ 234.96	$ 839.96
New York	605.00	307.78	912.78
Atlanta	605.00	227.92	832.92
Albuquerque	605.00	197.34	802.34

Existing Multi-Family Residence

City	Material	Labor	Total
Omaha	$ 605.00	$ 469.72	$ 1074.92
New York	605.00	615.56	1220.56
Atlanta	605.00	455.84	1060.84
Albuquerque	605.00	394.68	999.68

Air Economizer

Description/Assumptions--

The air economizer description/assumptions are idential to those described for the single family residence. Each of the eleven apartments is assumed to have its own air economizer system.

Costs--

Installed costs for the multi-family building are assumed to be identical to those described for the single family residence; except increased by a factor of eleven.

New Multi-Family Residence--

	Labor			
City	Elec	Sheet Metal	Mat.	Total
Omaha	$ 814	$ 616	$ 3410	$ 4840
Atlanta	781	550	3410	4741
Albuquerque	682	616	3410	4708
New York	1056	913	3410	5379

Existing Multi-Family Residence--

	Labor			
City	Elec	Sheet Metal	Mat.	Total
Omaha	$1045	$ 814	$ 3410	$ 5269
Atlanta	1012	726	3410	5148
Albuquerque	880	825	3410	5115
New York	1375	1210	3410	5995

Increased Domestic Hot Water Tank Insulation/Decreased Temperature

Description/Assumptions--
The description/assumption of this energy conservation technique are identical to those described for the single family residence. Each of the eleven apartments was considered to have its own domestic hot water tank.

Costs--
Costs are identical to those described for a single family residence; except increased by a factor of eleven.

New and Existing Multi-Family Residences--

City	Labor	Material	Total
Omaha	$ 110.00	$ 219.45	$ 329.45
Atlanta	90.20	219.45	309.65
Albuquerque	86.90	219.45	306.35
New York	133.10	219.45	352.55

Reflective Films on Glass

Description/Assumptions

The description/assumptions are identical to those described for the single family residence.

Costs--

Installed costs per square foot are identical to those described for the single family residence.

New and Existing Multi-Family Buildings--

City	Labor	Material	Total
Omaha	$1.00	$1.00	$2.00/ft^2
Atlanta	.82	1.00	1.82/ft^2
Albuquerque	.79	1.00	1.79/ft^2
New York	1.21	1.00	2.21/ft^2

Awnings

Description/Assumptions--

The awning description/assumptions are identical to those described for the single family residence.

Costs--

Installed costs per awning for both new and existing multi-family residences are identical to those detailed for the single family residence.

New and Existing Multi-Family Residence--

City	Labor	Material	Total
Omaha	$82.50	$ 472.45	$1816.20
Atlanta	75.13	472.45	1792.08
Albuquerque	74.25	472.45	1789.20
New York	91.63	472.45	1836.08

High Efficiency Lights

Description/Assumptions--

The description/assumptions for high efficiency lights is identical to those described for the single family residence.

Costs--

Installed costs are identical to those detailed in the description of the single family residence; except increased by a factor of eleven.

New Multi-Family Residence--

City	Labor	Material	Total
All	0	1782.00	1782.00

Existing Multi-Family Residence--

City	Labor	Material	Total
Omaha	$ 1885.51	$ 4290.00	$ 6175.51
New York	2426.05	4290.00	6716.05
Atlanta	1967.02	4290.00	6257.02
Albuquerque	1737.45	4290.00	6027.45

Insulation

Description/Assumptions--
Savings through added insulation can be realized by a continuous range of insulation levels. In reality, no continuous range of insulation levels exist. Rather, insulation levels are available in a finite number of sizes. Further, construction techniques may limit the amount of any type that can be applied to the building. Batt type insulation, for example, comes in limited depths of 3.5, 6 and 10 inches. Standard construction of outside residential walls employ 2x4 studs (1.5 x 3.5 actual dimensions) and is suitable only for 3.5 inch batts. To examine only realistic cases, only finite and feasible amounts and commercially available types of insulation are considered. These included:

- Add Insulation-Adding additional insulation to walls, walls below grade, and ceiling of both new and existing buildings.
- Add Glazing - Increasing window glazing on new and existing building by retrofitting with double and/or triple glazing.
- Alternate Construction- For new buildings, constructing exterior walls out of 2 x 6 studs, 2 feet on center with 6 inches of insulation and replacing fiberboard/plywood sheathing with 1 or 2 inches of styrofoam.
- Decreased Infiltration- Decreasing the infiltration portion of the heat load.

Costs for New and Existing Multi-Family Residences--

For each region and for both new and existing buildings, a number of cases of insulation were identified and costed. This approach was most cost effective level. (Tables B-5 through B-12). A number of assumptions were made regarding various insulation levels. These include:

- Wall construction costs for 2x6 outside walls assumes 2x6 studs are spaced two feet on center.
- Styrofoam sheathing on outside walls has an insulation value of R-5.41.
- Where 2x6 outside walls are used, extra costs for extension jambs on all windows, sliding glass doors and entrance doors were added to installed costs.
- The infiltration rate for the base buildings was assumed to be .75 and 1.00 air changes per hour for the new and existing building, respectively. Infiltration rates were reduced, conservatively, as added insulation, triple glazing, etc. were added.
- Material costs and labor rates were extracted from the Building Systems Cost Guide, 1976, Robert Snow Means Company Inc. (Reference 26) and were adjusted for each city.

TABLE B-5

MULTI-FAMILY RESIDENCE OMAHA INSULATION CONFIGURATIONS

CASE	WALLS	CEILING	BASEMENT	WINDOWS	DOORS	INFILTRATION	COMMENTS INSULATED COSTS
1	.5" sheet rock .45 2x4 studs 3.5" insulation 11.00 .5" fiberboard 1.32 4" common brick .44	.5" sheet rock .45 6" loose fill 13	.5" sheet rock .45 .75" styrofoam 3 12" blocks 2.27	Insulated Glass	Insulated Metal	.75 air changes per hour	Base new Multi-family
2.	.5" sheet rock .45 2x4 studs 3.5" insulation 11.00 1" styrofoam 5.41 4" common brick .44	.5" sheet rock .45 6" Batts 19	same	same	same	.60	186
3.	5" sheet rock .45 2x4 studs 3.5" insulation 11.00 2" styrofoam 10.82 4" common brick .44	.5" sheet rock .45 10" Batts 30.00	same	same	same	.45	2331
4.	.5" sheet rock .45 2x4 studs 3.5" insulation 11.00 2" styrofoam 10.82 4" common brick .44	.5" sheet rock .45 12" Batts 38.00	same	same	same	.45	2619
5.	same	same	same	Triple glazing	same	.375 4419	4419
6.	same	same	.5" sheet rock .45 .75" stryofoam 3.00 12" blocks 2.27 1" stryofoam 5.41	same	same	.375	4909
7	.5" sheet rock .45 2x6 studs 6" insulation 19.00 .5" fiberboard 1.32 4" common brick .44	same	.5" sheet rock .45 .75" styrofoam 3.00 12" blocks 2.27	Insulated Glass	same	.5	2208
8.	.5" sheet rock .45 2x6 studs 6" insulation 19.00 1" styrofoam 4" common brick .44	same	.5" sheet rock .45 .75" styrofoam 3.00 12" blocks 2.27 1" styrofoam 5.41	same	same	.45	2466
9.	same	same	same	triple glazing	same	.375	4263
10.	same	same	.5" Sheet rock .45 .75" styrofoam 3.00 12" blocks 2.27 1" styrofoam 5.41 .5" sheet rock .45 .75" styrofoam 3.00 12" blocks 2.27	same	same	.375	4757
11.	.5" sheet rock .45 2x6 studs 6" insulation 19.00 2" styrofoam 10,82 4" common brick .44	same		same	same	.375	5404

TABLE B- 6
NEW MULTI-FAMILY, ATLANTA - INSULATION CONFIGURATIONS

CASE	EXTERIOR WALLS	CEILING	WINDOWS	DOORS	INFILTRATION	COMMENTS/ INSTALLED COSTS
1	4" face brick 0.44 .5" gypsum board 0.45 3.5" batt insulation 11.00 2"x4" studs .5" gypsumboard 0.45	6" loose fill insul 13.00 2"x6" ceiling joists .5" gypsumboard 0.45	Single light (U = 1.13)	1.5" solid Wood slab (U = 0.49)	.75 air change per hour	Base Case - New
2	4" face brick 0.44 1" styrofoam 5.41 3.5" batt insulation 11.00 2x4 studs .5" gypsumboard 0.45	12" batts 38.00 2x6 joists .5 gypsumboard .45	Insulated glass double (¼" air) U - .65	same	.5	2575
3	4" face brick 0.44 2" styrofoam 10.82 3.5" batt insulation 11.00 2x4 studs .5" gypsumboard 0.45	same	same	same	.45	3860
4	4" face brick 0.44 .5" gypsumboard 0.45 6" batt insulation 19.00 2"x6" studs .5" gypsumboard 0.45	same	same	same	.50	3880
5	4" face brick 0.44 1" styrofoam 5.41 6" batt insulation 19.00 2"x6" studs .5" gypsumboard 0.45	same	same	same	.45	4040
6	same	same	Insulated glass plus storm window (U = 0.36)	same	.375	5675
7	4" face brick 0.44 2" styrofoam 10.82 6" batt insulation 19.00 2"x6" studs .5" gypsumboard 0.45	same	same	same	.375	6990

TABLE B- 7

NEW MULTI-FAMILY, NEW YORK - INSULATION CONFIGURATIONS

CASE	EXTERIOR WALLS	R	CEILING	R	BASEMENT	R	WINDOWS	DOORS	INFILTRATION	COMMENTS/ INSTALLED COSTS
1	4" face brick .5" fiberboard 3.5" batt insul. 2"x4" studs .5" gypsumbd.	0.44 1.32 11.00 4.35 0.45	6" loose fill insulation 2"x6" ceiling joist .5" gypsumbd.	13.00 7.45 0.45	12" conc. block .75" styrofoam .5" gypsumboard	2.27 4.06 0.45	Insulated glass double (¼"air) (U = 0.65)	1.75" steel solid polystro core (U - 0.47)	.75 air change per hour	Base
2	4" face brick 2" styrofoam 3.5" batt insul. 2"x4" studs .5" gypsumbd.	0.44 10.82 11.00 4.35 0.45	12" batt insul. 2"x6" joists .5" gypsumbd.	38.00 7.45 0.45	1" styrofoam 12" conc. block .75" styrofoam .5" gypsumbd.	5.41 2.27 4.06 0.45	same	same	.45	1685
3	4" face brick .5" fiberboard 6" batt insul. 2"x6" studs .5" gypsumbd.	0.44 1.32 19.00 7.45 0.45	same		12" conc. block .75" styrofoam .5" gypsumbd.	2.27 4.06 0.45	same	same	.50	3065
4	4" face brick 1" styrofoam 6" batt insul. 2"x6" studs .5" gypsumbd.	0.44 5.41 19.00 7.45 0.45	same		same		same	same	.45	2245
5	same		same		same		Insulated glass plus storms (U = 0.36)	same	.375	4155
6	4" face brick 2" styrofoam 6" batt insul. 2"x6" studs .5" gypsumbd.	0.44 10.82 19.00 7.45 0.45	same		1" styrofoam 12" conc. block .75" styrofoam .5" gypsumbd.	5.41 2.27 4.06 0.45	same	same	.375	5470

TABLE B- 8

NEW MULTI-FAMILY, ALBUQUERQUE - INSULATION CONFIGURATIONS

CASE	EXTERIOR WALLS		CEILING	R	BASEMENT	WINDOWS	DOORS	INFILTRATION	COMMENTS/ INSTALLED COSTS
1	.5" stucco 3.5" batt insulation 2"x4" studs .5" gypsumbd.	0.10 11.00 4.35 0.45	6" batt insul. 2"x6" ceiling joists .5" gypsumbd.	19.00 0.45	none	Single light (U = 1.13)	1.5" solid wood slab (U - 0.49)	.75 air change per hour	Base Case - New
2	.5" stucco 2" styrofoam 3.5" batt insulation 2"x4" studs .5" gypsumbd.	0.10 10.82 11.00 4.35 0.45	12" batt insul. 2"x6" joists .5" gypsumbd.	38.00 0.45	none	Insulated glass double (¼" air) (U = 0.65)	same	.45	4890
3	.5" stucco 6" batt insulation 2"x6" studs .5" gypsumbd	0.10 19.00 7.45 0.45	same		none	same	same	.50	4050
4	.5" stucco 1" styrofoam 6" batt insulation 2"x6" studs .5" gypsumbd.	0.10 5.41 19.00 7.45 0.45	same		none	same	same	.45	5315
5	same		same		none	Insulated glass plus storm window (U = 0.36)	same	.375	6915
6	.5" stucco 2" styrofoam 6" batt insulation 2"x6" studs .5" gypsumbd.	0.10 10.82 19.00 7.45 0.45	same		none	same	same	.375	8240

TABLE B-9

EXISTING MULTI-FAMILY - OMAHA - INSULATION CONFIGURATIONS

CASE	EXTERIOR WALLS		CEILING	R	BASEMENT	R	WINDOWS	DOORS	INFILTRATION	COMMENTS INSTALLED COST
1	4" face brick ½" plywood sheathing 3½" air space (2x4) ½" plaster	0.44 0.62 0.97 0.32	4" loose fill insul. ½" plaster (2x6)	9.00 0.32	12" conc. block	2.27	Single light U = 1.13	Solid wood U = 0.49	1.0 ACH	Base
2	4" face brick ½" plywood sheathing 3½" cellulose insul. ½" plaster	0.44 0.62 12.00 0.32	Blown-in Insul. 4" loose fill insul. ½" plaster	21.00 9.00 0.32	same		Single w/storms U = 0.56	same	0.80	6535
3	same		Blown-in Inusl. 4" loose fill insul ½" plaster	29.00 9.00 0.32	same		same	same	0.75	6685
4	same		same		12" conc. block 1" styrofoam ½" gypsumbd	2.27 5.41 0.45	same	same	0.75	8320
5	4" face brick ½" plywood sheathing 3½" Ureaformaldehyde ½" plaster	0.44 0.62 17.50 0.32	same		same		same	same	0.60	9795
6	same		same		12" conc. block	2.27	same	same	0.60	8160
7	same		Blown-in insul. 4" loose fill insul. ½" plaster	21.00 9.00 0.32	same		same	same	0.65	7010

TABLE B-10

EXISTING MULTI-FAMILY - ATLANTA - INSULATION CONFIGURATIONS

CASE	EXTERIOR WALLS	R	CEILING	R	EASEMENT	WINDOWS	DOORS	INFILTRATION	COMMENTS/ INSTALLED COSTS
1	4" face brick ½" plywood sheathing 3½" air space (2x4) ½" plaster	0.44 0.62 0.97 0.32	½" plaster (2x6)	0.32	None	Single light U = 1.13	Solid wood U = 0.49	1.0 ACH	Base Case
2	4" face brick ½" plywood sheathing 3½" cellulose Insul ½" plaster	0.44 0.62 12.00 0.32	Blown-in insul ½" plaster	22.00 0.32	None	Single with storms U = 0.56	same	0.80	6095
3	same		Blown-in insul. ½" plaster	30.00 0.32	None	same	same	0.78	6235
4	same		Blown-in insul. ½" plaster	38.00 0.32	None	same	same	0.75	6695
5	4" face brick ½" plywood sheathing 3½" Ureaformaldehyde ½" plaster	0.44 0.62 17.50 0.32	Blown-in insul. ½" plaster	22.00 0.32	None	same	same	0.65	7385
6	same		Blown-in insul. ½" plaster	30.00 0.32	None	same	same	0.63	7525
7	same		Blown-in insul ½" plaster	38.00 0.32	None	same	same	0.60	7985

TABLE B- 11

EXISTING MULTI-FAMILY - NEW YORK - INSULATION CONFIGURATIONS

CASE	EXTERIOR WALLS	CEILING R	BASEMENT R	WINDOWS	DOORS	INFILTRATION	COMMENTS INSTALLED COSTS
1	4" face brick 0.44 ½" plywood sheathing 0.62 3½" air space (2x4) 0.97 ½" plaster 0.32	4" loose fill insul. 9.00 ½" plaster 0.32 (2x6)	12" conc. block 2.27	Single light U = 1.13	Solid wood U = 0.49	1.0 ACH	Base
2	4" face brick 0.44 ½" plywood sheathing 0.62 3½" cellulose insul. 12.00 ½" plaster 0.32	Blown-in Insul. 21.00 4" loose fill insul. 9.00 ½" plaster 0.32	same	Single w/storms U = 0.56	same	0.80	7095
3	same	Blown-in Inusl. 29.00 4" loose fill insul 9.00 ½" plaster 0.32	same	same	same	0.75	7250
4	same	same	12" conc. block 2.27 1" styrofoam 5.41 ½" gypsumbd 0.45	same	same	0.75	9080
5	4" face brick 0.44 ½" plywood sheathing 0.62 3½" Ureaformaldehyde 17.50 ½" plaster 0.32	same	same	same	same	0.60	10615
6	same	same	12" conc. block 2.27	same	same	0.60	8785
7	same	Blown-in insul. 21.00 4" loose fill insul. 9.00 ½" plaster 0.32	same	same	same	0.65	8635

TABLE B-12

EXISTING MULTI-FAMILY - ALBUQUERQUE - INSULATION CONFIGURATIONS

CASE	EXTERIOR WALLS	R	CEILING	R	BASEMENT	WINDOWS	DOORS	INFILTRATION	COMMENTS/ INSTALLED COST
1	4" face brick ½" plywood sheathing 3½" air space (2x4) ½" plaster	0.44 0.62 0.97 0.32	½" plaster (2x6)	0.32	None	Single light U = 1.13	Solid wood U = 0.49	1.0 ACH	Base Case
2	4" face brick ½" plywood sheathing 3½" cellulose Insul. ½" plaster	0.44 0.62 12.00 0.32	Blown-in insul ½" plaster	22.00 0.32	None	Single with storms U = 0.56	same	0.80	5850
3	same		Blown-in insul. ½" plaster	30.00 0.32	None	same	same	0.78	5985
4	same		Blown-in insul. ½" plaster	38.00 0.32	None	same	same	0.75	6420
5	4" face brick ½" plywood sheathing 3½" Ureaformaldehyde ½" plaster	0.44 0.62 17.50 0.32	Blown-in insul. ½" plaster	22.00 0.32	None	same	same	0.65	7080
6	same		Blown-in insul. ½" plaster	30.00 0.32	None	same	same	0.63	7210
7	same		Blown-in insul ½" plaster	38.00 0.32	None	same	same	0.60	7645

Furnace Efficiency

Description/Assumptions--

The high efficiency furnace assumes that the furnace efficiency is increased from 65 percent to 80 percent.

Costs--

New Multi-Family Residence--

It was assumed that the high efficiency furnace was installed in the new building at the time of construction. No additional installation costs were assumed.

City	Material	Total
Omaha	$ 1650	$ 1650
Atlanta	1650	1650
New York	1650	1650
Albuquerque	1650	1650

Existing Multi-Family Residence--

City	Labor		Material	Total
	Pipefitter	Sheet Metal		
Omaha	$ 1353	$ 1408	$ 4950	$ 7711
Atlanta	1144	1254	4950	7348
New York	1496	2101	4950	8547
Albuquerque	1892	1430	4950	8272

Retail Store

Energy Conservation Techniques analyzed for both new and existing Retail Stores include:

- Minimum Ventilation
- Air Econimizer
- Vent Heat Recovery
- Reflective Film
- Awnings
- Double/Triple Glazing
- Reduced Light Level
- Reduced Light Schedule
- Night Setback
- Additional Wall Insulation
- Additional Wall and Roof Insulation
- Water Tank Insulation/Decreased Temperature
- High Efficiency Furnace

Insulation - New Construction

Insulation Package 1 (North Central and West)--

Increase the thermal resistance of the structure by putting 2 inches of rigid insulation on the walls instead of 1 inch during construction. The cost of this ECT is the difference between the costs of installing the thicker insulation and those for the thinner.

Insulation Package 2 (North Central and West)--

In addition to the modifications of package 1, place an additional 2 inches of insulation in the roof during initial construction of the structure. The cost is the difference between the standard level of insulation and the new level.

Insulation Package3 (North East and South)--

Increase the thermal resistance of the curtainwalls by adding 2 inches more rigid insulation to the walls during initial construction. The cost of the ECT is the difference between installing the two levels of insulation.

Insulation Package 4 (North East and South)--

Modify structure as per package 3 and add 2 inches more insulation to the roof. The ECT cost is again the difference between installing the two levels.

Insulation - Existing Construction

Insulation Package 1 (North Central and West)--

Increase the thermal resistance of the structure by adding 2 inches of rigid insulation face with 1/2" gypsumboard to the inside of the exterior walls.

Insulation Package 2 (North Central and West)--

Increase the thermal resistance of the walls as per package one and add 4 inches of rigid insulation to the roof during normal reroofing.

Insulation Package 3 (North East and South)--

Increase the thermal resistance of the metal curtainwall by adding 4 inches of rigid insulation to the inside of the exterior walls faced with 1/2 inch gypsumboard.

Insulation Package 4 (North East and South)--

Increase the termal resistance of the curtainwall as per package 3 and add 4 inches of rigid insulation to the roof during normal reroofing.

NEW RETAIL STORE INSULATION PACKAGE COSTS (NEW CONSTRUCTION)

City	Additional Insulation	Labor Adj.*	Material Adj. *	Cost Per Sq. Ft.	Sq. Ft. of Surface	Total Cost
Omaha	1" in walls	0.90	0.98	$0.19	4,195	$ 800
	2" in roof	0.90	0.98	$0.61	5,035	$3,070
	Walls and Roof					$3,870
New York	2" in walls	1.25	1.18	$0.73	4,195	$3,060
	2" in roof	1.25	1.18	$0.77	5,035	$3,880
	Walls and Roof					$6,940
Albuquerque	1" in walls	0.94	0.80	$ .51	4,195	$2,140
	2" in roof	0.94	0.80	$ .54	5,035	$2,720
	Walls and Roof					$4,860
Atlanta	2" in walls	0.83	0.90	$ .54	4,195	$2,260
	2" in roof	0.83	0.90	$ .56	5,035	$2,820
	Walls and Roof					$5,080

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. Refer to table B-13 for National Average Material and Labor Rates.

RETAIL STORE INSULATION PACKAGE COSTS (EXISTING CONSTRUCTION)

CITY	ADDITIONAL INSULATION	LABOR ADJ *	MATERIAL ADJ *	COST PER SQ. FT.	SQ. FT. OF SURFACE	TOTAL COST
Omaha	2" to walls	0.90	0.98	$0.84	4,195	$ 3,520
	4" to roof	0.90	0.98	$1.23	5,035	$ 6,190
	Walls & Roof					$ 9,710
New York	4" to walls	1.25	1.18	$1.27	4,195	$ 5,330
	4" to roof	1.25	1.18	$1.55	5,035	$ 7,800
	Walls & Roof					$13,130
Albuquerque	2" to walls	0.94	0.80	$0.75	4,195	$ 3,150
	4" to roof	0.94	0.80	$1.09	5,035	$ 5,490
	Walls & Roof					$ 8,640
Atlanta	4" to walls	0.83	0.80	$1.15	4,195	$ 4,820
	4" to roof	0.83	0.80	$1.14	5,035	$ 5,740
	Walls & Roof					$10,560

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. Refer to Table B-13 for national average material and labor rates.

TABLE B-13 COMMERCIAL SECTOR MATERIAL/LABOR RATES *

Item		Labor Cost	Material Cost	Unit	Labor Type
1" rigid insulation on walls		$0.19	$0.22	FT^2	CP
2" rigid insulation on walls		$0.20	$0.46	FT^2	CP
½" gypsumboard on walls		$0.14	$0.14	FT^2	CP
4" rigid insulation on walls		$0.15	$0.92	FT^2	CP
2" rigid insulation on roof		$0.19	$0.46	FT^2	CP
4" rigid insulation on roof		$0.37	$0.92	FT^2	CP
Install interior glass windows over present		$2.09	$2.09	FT^2	GL
Install reflective film		$1.00	$1.00	FT^2	General
Install triple pane windows		$3.15	$7.91	FT^2	GL
Install double pane windows		$2.52	$5.27	FT^2	GL
Heat exchanger		$0.20	$0.30	CFM	PF
Heaters :	18KW	$150	$342	Heater	EL
	40KW	$150	$606	Heater	EL
	50KW	$150	$736	Heater	EL
	60KW	$150	$867	Heater	EL

CP = carpenter
GL = glazier
PF = pipefilter
EL = electrician

* The above table portrays the national average material and labor costs incurred to install the listed items. For instance, installation of one square foot of one inch thick rigid insulation would cost $0.19 for labor and $0.22 for materials on the average nationwide. For a specific location, these costs would be modified by the appropriate adjustment factors.

Window Treatment - New Construction

Window Treatment #1--

Install triple glazed insulated windows rather than double glazed insulated windows in new construction. This will increase the thermal resistance of the window, thus decreasing transmission heat loss through it. Cost to install the ECT is the difference in cost between double and triple glazed windows.

Window Treatment #2--

Install double glazed, insulating, reflective coated glass windows in place of normal double glazed insulated windows in new construction. The reflective coating decreases the amount of solar radiation transmitted through the glass thus decreasing cooling loads. Use the reflective glass for both window and door glass areas.

CITY	WINDOW ECT	LABOR ADJ *	MATERIAL ADJ *	COST PER SQ. FT.	SQ FT OF SURFACE	TOTAL COST
Omaha	Triple	0.80	0.98	$3.09	140	$430
	Reflect	0.80	0.98	$3.11	245	$760
New York	Triple	1.18	1.18	$3.86	140	$540
	Reflect	1.18	1.18	$3.74	245	$916
Albuquerque	Triple	0.72	0.80	$2.56	140	$360
	Reflect	0.72	0.80	$2.54	245	$622
Atlanta	Triple	0.88	0.90	$2.93	140	$410
	Reflect	0.88	0.90	$2.85	245	$700

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. Refer to Table B-13 for national average material and labor rates.

Window Treatment-Existing Construction

Window Treatment # 1--

Reduce the transmission heat losses through the window by the addition of an interior, glass "storm" window. This provides the same thermal effect as an insulated glass window with 1 inch air space between panes (i.e., double glazing).

Window Treatment # 2--

Reduce heat gains through the windows by installing a reflective film over the inside of the window pane. Current films have a lifetime of 6 to 7 years, therefore, costs assume three replacements over twenty years. Cost is present value of three installations. Films are also installed on the doors.

City	Window ECT	Labor Adj.*	Material Adj. *	Cost Per Sq. Ft.	Sq. Ft. of Surface	Total Cost
Omaha	Dbl. Glz. Film	0.80 0.86	0.98 0.98	$3.72 $1.84	140 245	$ 520 $1180
New York	Dbl. Glz. Film	1.18 1.27	1.18 1.18	$4.93 $2.45	140 245	$ 690 $1580
Albuquerque	Dbl. Glz. Film	0.72 0.67	0.80 0.80	$3.18 $1.47	140 245	$ 450 $ 950
Atlanta	Dbl. Glz. Film	0.88 0.72	0.90 0.90	$3.72 $1.62	140 245	$ 520 $1040

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. Refer to Table B-13 for national average material and labor rates.

Reduce Ventilation Rates

This energy conservation measure involves decreasing the fresh air ventilation level from 14 CFM per person to 7 CFM per person and closing the fresh air dampers completely from 9:00 pm to 6:00 am. This involves adjusting the minimum position of the fresh air intake damper and resetting the controls of the existing equipment. An engineering cost estimate for these modifications was $140.

City	Labor Adj.*	Total Cost
Omaha	0.89	$125
New York	1.21	$170
Albuquerque	0.79	$110
Atlanta	0.82	$115

Energy Reclamation From Exhaust Air

Energy reclamation from exhaust air is accomplished by installing a heat exchanger which will allow the exhaust air to pre-condition the intake air. The purpose of this ECT is to save energy by using the exhaust air to preheat the intake air during the heating season. In the cooling season, the idea is to use the cool exhaust air to remove some of the heat from the intake air. The cost of installing a heat exchanger was estimated as $0.50 per CFM of exhaust air. The heat exchanger is sized on the basis of the air conditioning CFM.

City	Labor Adj.*	Material Adj.*	Cost Per CFM	AC Fan	Total Cost
Omaha	0.89	0.98	$0.50	4800	$2,400
New York	1.21	1.18	$0.67	4800	$3,220
Albuquerque	0.79	0.80	$0.45	4800	$2,160
Atlanta	0.82	0.90	$0.48	4800	$2,300

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. Refer to Table B-13 for national average material and labor rates.

Awnings

The purpose of installing an awning over the large window in the retail store is to decrease the solar insolation, thus decreasing the energy needed for air conditioning. The awning used is a canvas, roll-up type that has a national cost of $50 for labor and $100 for materials. There is no difference in cost between new and existing buildings.

City	Labor Adj.*	Material Adj. *	Total Cost
Omaha	0.89	0.98	$140
New York	1.21	1.18	$180
Albuquerque	0.79	0.80	$120
Atlanta	0.82	0.90	$130

Night Setback

The effect of this energy conservation technology is only felt by the heating system. It involves setting the thermostat back from 68°F to 63°F during the hours 10:00 pm to 6:00 am. This decreases the amount of energy required for heating because the system is being controlled at a lower temperature.

The setback is accomplished automatically with a clock-type thermostat. Since the building is a single zone system, only the present heating system control thermostat needs to be replaced. The national average labor rate was $24 per installation, and the material was $89.27 per installation.

CITY	LABOR* ADJUSTMENT	MATERIAL* ADJUSTMENT	COST OF INSTALLATION
Omaha	0.89	0.98	$109
New York	1.21	1.18	$140
Albuquerque	0.79	0.80	$ 90
Atlanta	0.82	0.90	$100

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. Refer to Table B-13 for national average material and labor rates.

Insulation of Hot Water Tank

The addition of fiberglass heating equipment insulation (R-6) with a vinyl cover to the hot water tank will increase its thermal resistance, thus decreasing the standby losses from the tank to the interior space. This will decrease the amount of energy needed to keep the water at the specified temperature. It will, also, decrease the amount of internal load that the cooling system must remove. The contractor installed cost for this ECT was $ 0.42 per square foot for labor and $ 0 76 per square foot for materials.

CITY	LABOR ADJ	MATERIAL ADJ*	COST PER SQ FT*	SQ FT OF SURFACE	TOTAL COST
Omaha	0.89	0.98	$1.11	27	$30.00
New York	1.21	1.18	$1.40	27	$38.00
Albuquerque	0.79	0.80	$0.94	27	$25.00
Atlanta	0.82	0.90	$1.03	27	$28.00

High Efficiency Furnace

The high efficiency furnace assumes that the furnace efficiency is increased from 55 percent to 80 percent for gas and oil fired heating systems. The high efficiency furnace is not applicable to electric resistance heating, since 100 percent efficiency is assumed for that case.

The additional material cost was $320 for both new and existing construction. No additional labor costs were added for installation in existing constructing since it was assumed that the high efficiency furnace was installed with the solar system.

Air Economizer

The purpose of an air economizer is to decrease the amount of energy required for air conditioning by using outside air for cooling. The air economizer is a control package. When the thermostat calls for cooling and the outdoor air temperature and humidity are in a prescribed range, the system introduces outside air rather than turning on the mechanical cooling. For a new building, the cost is simply the additional cost of the controls ($ 180) when the HVAC system is installed. While in an existing system, the cost to retrofit will, of course, be higher ($ 216) because of additional labor.

City	Labor Adj.*	Material Adj. *	Cost for New	Cost for Existing
Omaha	0.89	0.98	$176	$200
New York	1.21	1.18	$212	$260
Albuquerque	0.79	0.80	$145	$175
Atlanta	0.82	0.90	$160	$185

Schools

Energy conservation techniques analyzed for new and existing school buildings include:

- Insulation
  - Added wall insulation
  - Added wall and ceiling insulation
- Window Treatment
  - Windows covered with reflective coating
  - Added pane of glass to windows
- Hot Water Tank Insulated, Maximum Hot Water Temperature Reduced to 130°F
- Air Economizer
- Night Setback; Cooling Off At Night
- Shading
- Reduced Ventilation

Insulation- New Construction

Insulation Package 1 (North Central and West)--

Increase the thermal resistance of the structure by putting 2 inches of rigid insulation on the walls instead of 1 inch during construction. The cost of this ECT is the difference between the costs of installing the thicker insulation and those for the thinner.

Insulation Package 2 (North Central and West)--

In addition to the modifications of package 1, place an additional 2 inches of insulation in the roof during initial construction of the structure. The cost is again, the difference between the standard level of insulation and the new level.

Insulation Package 3 (North East and South)--

Increase the thermal resistance of the curtainwalls by adding 2 inches more rigid insulation to the walls during initial construction. The cost of the ECT is the difference between installing the two levels of insulation.

Insulation Package 4 (North East and South)--

Modify structure as per package 3 and add 2 inches more insulation to the roof. The ECT cost is again the difference between installing the two levels.

NEW SCHOOL INSULATION PACKAGE COSTS

City	Additional Insulation	Labor Adj.*	Material Adj.*	Cost Per Sq. Ft.	Sq. Ft. of Surface	Total Cost
Omaha	1" in walls	0.90	0.98	$0.19	9,920	$ 1,880
	2" in roof	0.90	0.98	$0.61	39,750	$24,250
	Walls and Roof					$26,130
New York	2" in walls	1.25	1.18	$0.73	9,920	$ 7,240
	2" in roof	1.25	1.18	$0.77	39,750	$30,600
	Walls and Roof					$37,840
Albuquerque	1" in walls	0.94	0.80	$ .51	9,920	$ 5,060
	2" in roof	0.94	0.80	$ .54	39,750	$21,460
	Walls and Roof					$26,520
Atlanta	2" in walls	0.83	0.90	$ .54	9,920	$ 5,360
	2" in roof	0.83	0.90	$ .56	39,750	$22,260
	Walls and Roof					$27,620

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. Refer to table B-13 for national average material and labor rates.

Insulation - Existing Construction

Insulation Package 1 (North Central and West)--

Increase the thermal resistance of the structure by adding 2 inches of rigid insulation face with 1/2 inch gypsumboard to the inside of the exterior walls.

Insulation Package 2 (North Central and West)--

Increase the thermal resistance of the walls as per package one and add 4 inches of rigid insulation to the roof during normal reroofing.

Insulation Package 3 (North East and South)--

Increase the thermal resistance of the metal curtainwall by adding 4 inches of rigid insulation to the inside of the exterior walls faced with 1/2 gypsumboard.

Insulation Package 4 (North East and South)--

Increase the thermal resistance of the curtainwall as per package 3 and add 4 inches of rigid insulation to the roof during normal reroofing.

EXISTING SCHOOL INSULATION PACKAGE COSTS

CITY	ADDITIONAL INSULATION	LABOR ADJ *	MATERIAL ADJ *	COST PER SQ. FT.	SQ. FT. OF SURFACE	TOTAL COST
Omaha	2" to walls	0.90	0.98	$0.84	9,920	$ 8,330
	4" to roof	0.90	0.98	$1.23	39,750	$48,890
	Walls & Roof					$57,220
New York	4" to walls	1.25	1.18	$1.27	9,920	$12,600
	4" to roof	1.25	1.18	$1.55	39,750	$61,610
	Walls & Roof					$74,210
Albuquerque	2" to walls	0.94	0.80	$0.75	9,920	$ 7,440
	4" to roof	0.94	0.80	$1.09	39,750	$43,330
	Walls & Roof					$50,770
Atlanta	4" to walls	0.83	0.80	$1.15	9,920	$11,410
	4" to roof	0.83	0.80	$1.14	39,750	$45,320
	Walls & Roof					$56,730

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. Refer to Table B-13 for national average material and labor rates.

Window Treatment - New Construction

Window Treatment #1--

Install triple glazed insulated windows rather than double glazed insulated windows in new construction. This will increase the thermal resistance of the window, thus decreasing transmission heat loss through it. Cost to install the ECT is the difference in cost between double and triple glazed windows.

Window Treatment # 2--

Install double glazed, insulating, reflective coated glass windows in place of normal double glazed insulated windows in new construction. The reflective coating decreases the amount of solar radiation transmitted through the glass thus decreasing cooling loads.

CITY	WINDOW ECT	LABOR ADJ *	MATERIAL ADJ*	COST PER SQ. FT.	SQ FT OF SURFACE	TOTAL COST
Omaha	Triple	0.80	0.98	$3.09	1,700	$5,250
	Reflect	0.80	0.98	$3.11	1,700	$5,290
New York	Triple	1.18	1.18	$3.86	1,700	$6,560
	Reflect	1.18	1.18	$3.74	1,700	$6,360
Albuquerque	Triple	0.72	0.80	$2.56	1,700	$4,350
	Reflect	0.72	0.80	$2.54	1,700	$4,320
Atlanta	Triple	0.88	0.90	$2.93	1,700	$4,980
	Reflect	0.88	0.90	$2.85	1,700	$4,850

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. National labor and material rates displayed on Table B-13.

Window Treatment - Existing Construction

Window Treatment #1--

Reduce the transmission heat losses through the window by the addition of an interior, glass "storm" window. This provides the same thermal effect as an insulated glass window with 1 inch air space between panes (i.e., double glazing).

Window Treatment #2--

Reduce heat gains through the windows by installing a reflective film over the inside of the window pane. Current films have a lifetime of 6 to 7 years, therefore, costs assume three replacements over twenty years. Cost is present value of three installations. Install films on doors also.

City	Window ECT	Labor Adj.*	Material Adj.*	Cost Per Sq. Ft.	Sq. Ft. of Surface	Total Cost
Omaha	Dbl. Glz.	0.80	0.98	$3.72	1,700	$ 6,320
	Film	0.86	0.98	$1.84	1,700	$ 8,220
New York	Dbl. Glz.	1.18	1.18	$4.93	1,700	$ 8,380
	Film	1.27	1.18	$2.45	1,700	$10,950
Albuquerque	Dbl. Glz.	0.72	0.80	$3.18	1,700	$ 5,400
	Film	0.67	0.80	$1.47	1,700	$ 6,570
Atlanta	Dbl. Glz.	0.88	0.90	$3.72	1,700	$ 6,320
	Film	0.72	0.90	$1.62	1,700	$ 7,240

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. National labor and material rates displayed on Table B-13.

Insulation of Hot Water Tank

The addition of vinyl clad fiberglass insulation blanket (R-6) to the hot water tank will increase its thermal resistance and decrease the standby losses from the tank to the interior space. This will decrease the amount of energy needed to keep the water at the specified temperature. The contractor installed cost used for this ECT was $ 0.19 per square foot for labor and $0.11 per square foot for materials.

City	Labor Adj. *	Material Adj. *	Labor Cost	Material Cost	Cost Per Sq. Ft.	Sq. Ft. of Surface	Total Cost
Omaha	0.89	0.98	$0.17	$0.11	$0.28	68	$19
New York	1.21	1.18	$0.23	$0.13	$0.46	68	$31
Albuquerque	0.79	0.80	$0.15	$0.09	$0.24	68	$16
Atlanta	0.82	0.90	$0.16	$0.10	$0.26	68	$18

Air Economizer

Install an air economizer control circuit and necessary sensor hardware on the cooling plant of the new schools. When the outdoor air temperature and relative humidity are within prescribed limits and the thermostat is calling for cooling, the economizer will introduce outdoor air and distribute it through the building rather than turning on the mechanical cooling equipment. For a more detailed description of how the economizer works, see the appendix on single family/multi-family ECT costs. The additional cost of a roof top packaged multizone unit with air economizer over that of the package unit without is about $ 1000. 00.

City	Material Adjustment *	Cost of ECT
Omaha	0. 98	$1000
New York	1. 18	$1200
Albuquerque	0. 80	$820
Atlanta	0. 90	$920

Additions/Alternations to HVAC System

Adjust the minimum setting of the outdoor air intake dampers. This decreases the amount of outdoor air that must be conditioned to the desired interior air characteristics. This effects savings during both heating and cooling. The labor requirements are 1 day per system for the multi-zone rooftop system on new buildings and 3 days per unit ventilation system in the existing building.

City	Labor Adj. *	Labor Rate	Cost Per Hour	Hours Per System	Existing Schools	New Schools
Omaha	0.89	$28	$25	24	$600	
	0.89	$28	$25	8		$200
New York	1.21	$28	$34	24	$820	
	1.21	$28	$34	8		$270
Albuquerque	0.79	$28	$22	24	$530	
	0.79	$28	$22	8		$180
Atlanta	0.82	$28	$23	24	$550	
	0.82	$28	$23	8		$180

*These are geographical cost adjustment factors based on a value of 1.00 for the national average.

Night Setback of Thermostat

The effect of this ECT is to shut off the cooling system at night and lower the temperature at which the heating system is controlled. In the summer this saves energy due to shutting down the cooling in the winter, heating energy is decreased due to controlling at the lower temperature. The addition of a time clock control is necessary to effect the ECT. It was assumed that retrofit would cost 20% more than new construction. The installed cost used was $100 for labor and $ 100 for materials for new construction.

City	Labor * Adjustment	Material * Adjustment	Cost of Control For New System	Retrofit Cost For Existing System
Omaha	1.00	0.98	$200	$240
New York	1.31	1.18	$250	$300
Albuquerque	0.84	0.80	$170	$200
Atlanta	0.97	0.90	$190	$230

Shading

Shading was accomplished in the simulation by reducing the energy transmitted through the east and west windows by 60 percent and the south window by 90 percent. The technique was not priced, since little information exists on the cost of shading. Therefore, the building owner/operator must weigh energy savings against actual costs.

Office Buildings

Energy Conservation Techniques analyzed for both new and existing Office Buildings include:

- Reflective Film
- Shading
- Double Glazing[4]
- Reduced Lighting
- Night Setback
- Reheat Optimization[4]
- Increased Wall Insulation
- Increased Wall and Roof Insulation
- Reduced Hot Water
- Convert to VAV[4]
- Energy Reclamation from Exhaust Air
- Triple Glazing[5]
- Hydronic Control From Zone Thermostat[5] With Night Setback

[4] CVTR Only

[5] VAV Only

Insulation - New Construction

Insulation Package 1 (North Central and West)--

Increase the thermal resistance of the structure by putting 2 inches of rigid insulation on the walls instead of 1 inch during construction. The cost of this ECT is the difference between the costs of installing the thicker insulation and those for the thinner.

Insulation Package 2 (North Central and West)--

In addition to the modifications of package 1, place an additional 2 inches of insulation in the roof during initial construction of the structure. The cost is, again, the difference between the standard level of insulation and the new level.

Insulation Package 3 (North East and South) --

Increased the thermal resistance of the curtainwalls by adding 2 inches more rigid insulation to the walls during initial construction. The cost of the ECT is the difference between installing the two levels of insulation.

Insulation Package 4 (North East and South) --

Modify structure as per package 3 and add 2 inches more insulation to the roof. The ECT cost is again the difference between installing the two levels.

NEW OFFICE BUILDING INSULATION PACKAGE COSTS

City	Additional Insulation	Labor Adj. *	Material Adj. *	Cost Per Sq. Ft.	Sq. Ft. of Surface	Total Cost
Omaha	1" in walls	0.90	0.98	$0.19	10,080	$ 1,920
	2" in roof	0.90	0.98	$0.61	10,000	$ 6,100
	Walls and Roof					$ 8,020
New York	2" in walls	1.25	1.18	$0.73	10,080	$ 7,360
	2" in roof	1.25	1.18	$0.77	10,000	$ 7,700
	Walls and Roof					$15,060
Albuquerque	1" in walls	0.94	0.80	$ .51	10,080	$ 5,140
	2" in roof	0.94	0.80	$ .54	10,000	$ 5,400
	Walls and Roof					$10,540
Atlanta	2" in walls	0.83	0.90	$ .54	10,080	$ 5,440
	2" in roof	0.83	0.90	$ .56	10,000	$ 5,600
	Walls and Roof					$11,040

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. National average material and labor rates are on Table B-13.

Insulation - Existing Construction

Insulation Package (North Central and West)--

Increase the thermal resistance of the structure by adding 2 inches of rigid insulation face with 1/2 inch gypsumboard to the inside of the exterior walls.

Insulation Package 2 (North Central and West)--

Increase the thermal resistance of the walls as per package one and add 4 inches of rigid insulation to the roof during normal reroofing.

Insulation Package 3 (North East and South)--

Increase the thermal resistance of the metal curtainwall by adding 4 inches of rigid insulation to the inside of the exterior walls faced with 1/2 inch gypsumboard.

Insulation Package 4 (North East and South)--

Increased the thermal resistance of the curtainwall as per package 3 and add 4 inches of rigid insulation to the roof during normal reroofing.

EXISTING OFFICE BUILDING INSULATION PACKAGE COSTS

CITY	ADDITIONAL INSULATION	LABOR ADJ*	MATERIAL ADJ*	COST PER SQ. FT.	SQ. FT. OF SURFACE	TOTAL COST
Omaha	2" to walls	0.90	0.98	$0.84	10,080	$ 8,470
	4" to roof	0.90	0.98	$1.23	10,000	$12,300
	Walls & Roof					$20,770
New York	4" to walls	1.25	1.18	$1.27	10,080	$12,800
	4" to roof	1.25	1.18	$1.55	10,000	$15,500
	Walls & Roof					$28,300
Albuquerque	2" to walls	0.94	0.80	$0.75	10,080	$7,560
	4" to roof	0.94	0.80	$1.09	10,000	$10,900
	Walls & Roof					$18,460
Atlanta	4" to walls	0.83	0.80	$1.15	10,080	$11,590
	4" to roof	0.83	0.80	$1.14	10,000	$11,400
	Walls & Roof					$22,990

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. National average material and labor rates on Table 13.

Window Treatment - New Construction

Window Treatment 1--

Install triple glazed insulated windows rather than double glazed insulated windows in new construction. This will increase the thermal resistance of the window, thus decreasing transmission heat loss through it. Cost to install the ECT is the difference in cost between double and triple glazed windows.

Window Treatment 2--

Install double glazed, insulating, reflective coated glass windows in place of normal double glazed insulated windows in new construction. The reflective coating decreases the amount of solar radiation transmitted through the glass thus decreasing cooling loads.

CITY	WINDOW ECT	LABOR ADJ*	MATERIAL ADJ*	COST PER SQ. FT.	SQ FT OF SURFACE	TOTAL COST
Omaha	Triple	0.80	0.98	$3.09	4,320	$13,350
	Reflect	0.80	0.98	$3.11	4,320	$13,340
New York	Triple	1.18	1.18	$3.86	4,320	$16,680
	Reflect	1.18	1.18	$3.74	4,320	$16,160
Albuquerque	Triple	0.72	0.80	$2.56	4,320	$11,060
	Reflect	0.72	0.80	$2.54	4,320	$10,970
Atlanta	Triple	0.88	0.90	$2.93	4,320	$12,660
	Reflect	0.88	0.90	$2.85	4,320	$12,310

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. National average material and labor rates shown on Table B-13.

Window Treatment - Existing Construction

Window Treatment 1--

Reduce the transmission heat losses through the window by the addition of an interior, glass "storm" window. This provides the same thermal effect as an insulated glass window with 1 inch air space between panes (i.e., double glazing).

Window Treatment 2--

Reduce heat gains through the windows by installing a reflective film over the inside of the window pane. Current films have a lifetime of 6 to 7 years, therefore, costs assume three replacements over twenty years. Cost is the present value of these installations.

City	Window ECT	Labor Adj.*	Material Adj.*	Cost Per Sq. Ft.	Sq. Ft. of Surface	Total Cost
Omaha	Dbl. Glz.	0.80	0.98	$3.72	4,320	$16,070
	Film	0.86	0.98	$1.84	4,320	$10,590
New York	Dbl. Glz.	1.18	1.18	$4.93	4,320	$21,300
	Film	1.27	1.18	$2.45	4,320	$10,590
Albuquerque	Dbl. Glz.	0.72	0.80	$3.18	4,320	$13,740
	Film	0.67	0.80	$1.47	4,320	$ 6,350
Atlanta	Dbl. Glz.	0.88	0.90	$3.72	4,320	$16,070
	Film	0.72	0.90	$1.62	4,320	$ 7,000

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. National average material and labor rates shown on Table B-13.

Night Setback

The purpose of this energy conservation technology is to decrease the amount of energy needed for heating. This is accomplished by lowering the temperature at which the base board heaters are controlled. The addition of a time clock is necessary to effect the ECT.

As per Means Construction Cost Data book, retrofit was assumed to cost 20% more than new construction. The average installed cost was $100 for labor and $100 for materials for new construction.

City	Labor* Adjustment	Material* Adjustment	Cost of Control For New System	Retrofit Cost For Existing System
Omaha	1.00	0.98	$200	$240
New York	1.31	1.18	$250	$300
Albuquerque	0.84	0.80	$170	$200
Atlanta	0.97	0.90	$190	$230

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. National average material and labor rates shown on Table B-13.

Energy Reclamation From Exhaust Air

Energy reclamation from exhaust air is accomplished by installing a heat exchanger which will alow the exhaust air to precondition the intake air. The purpose of this ECT is to save energy by using the exhaust air to preheat the intake air during the heating season. In the cooling season, the idea is to use the cool exhaust air to remove some of the heat from the intake air. The cost of installing a heat exchanger was estimated as $0.50 per CFM of exhaust air. The heat exchanger is sized on the basis of the minimum exhaust CFM.

City	Labor Adj.*	Material Adj. *	Cost Per CFM	Min. CFM	Total Cost
Omaha	0.89	0.98	$0.50	9000	$4,500
New York	1.21	1.18	$0.67	9000	$6,030
Albuquerque	0.79	0.80	$0.45	9000	$4,050
Atlanta	0.82	0.90	$0.48	9000	$4,320

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. National average material and labor rates shown on Table B-13.

Convert CVTR To VAV

Conversion of the system involves some extensive alterations and additions to the existing setup. Some of the things that must be done are: install dampers in the main branch to each zone to control the amount of inlet air admitted to each zone, install motors to drive each of these dampers and tie the operation of these motors to the thermostat in each zone. The engineering cost estimate to accomplish this conversion is $ 34,400 for the size of the building being studied.

City	Labor Adjustment *	Materials Adjustment*	Conversion Cost
Omaha	0.89	0.98	$30,000
New York	1.21	1.18	$38,300
Albuquerque	0.79	0.80	$25,000
Atlanta	0.82	0.90	$27,600

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. National average material and labor rates shown on Table B-13

Alter Control of Hydronic Loop

Under current practices, the hydronic loop of a Variable Air Volume (VAV) system is controlled with outdoor air reset. This means that, as the outdoor temperature drops, the water temperature of the hydronic loop is raised to compensate for the higher skin transmission losses. However, this reset is designed on the basis of maintaining indoor temperature during a coldest night when there are no loads (e.g., solar, people or lighting) contributing heat to the building's interior. Thus, the hydronic loop always reacts as if there were no internal loads. This means that any internal loads have the effect of increasing the cooling requirements rather than decreasing the heating requirements.

The energy conservation technology designed to prevent this problem involves altering the hydronic system such that its temperature in each zone increases as the temperature inside the building decreases. With this arrangement, internal loads are allowed to balance off skin transmission losses, thus decreasing the energy required for heating.

The following changes are made during the construction of the building. Each zone is given its own hydronic loop. This involves the addition of 600 feet of extra copper tubing at $ 1.10/linear foot for materials and $ 2.58/linear foot for labor; check valve for each zone at $70/valve for materials and $28/valve for labor; relays to operate valves at $25/ zone for materials and $30/zone for labor; and installing thermostats to control the zone's hydronic loop in each zone at a cost of $ 50 for material and $40 for labor per zone. There are 12 zones in the building which must be altered.

CITY	LABOR ADJ*	MATERIAL ADJ*	TOTAL COST
Omaha	0.97	0.98	$ 5000
New York	1.12	1.18	$ 5880
Albuquerque	0.92	0.80	$ 4430
Atlanta	0.82	0.90	$ 4390

*These are geographical cost adjustment factors based on a value of 1.00 for the national average. National average material and labor rates shown on Table B-13.

APPENDIX C
FUEL PRICE SCENARIOS

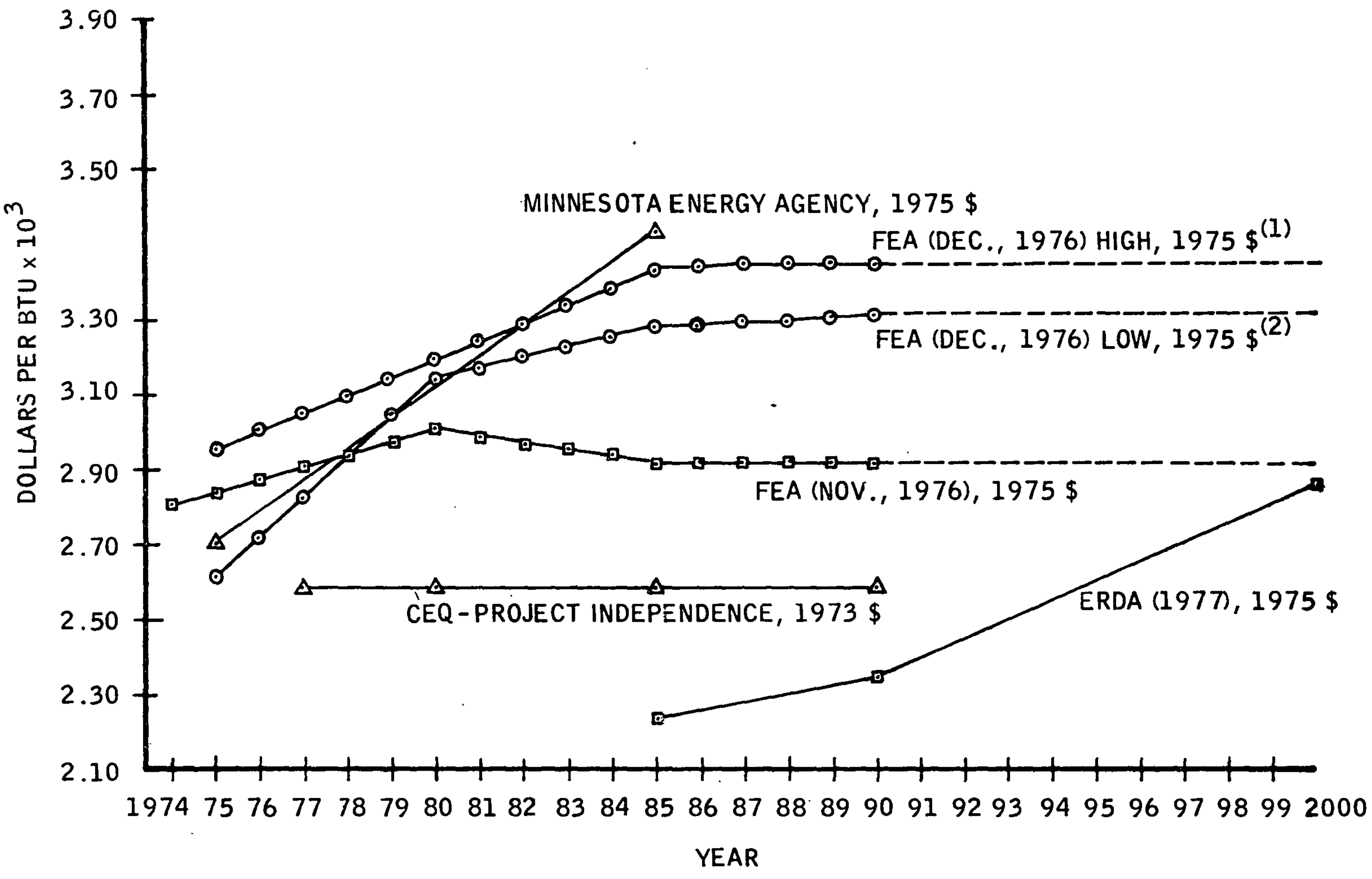
INTRODUCTION

The research of looking at price projection turned up several different analyses. These estimates are plotted in Figures C-1 to C-3. Data was obtained from Minnesota Energy Agency, CEQ-Project Independence, ERDA, and two different FEA projections.

Fuel prices selected for use in the mixed strategies analysis were obtained from the Federal Energy Agency (dated December 1976). Price obtained included the following information:

- Prices were given for ten regions of the Continental United States.
- Prices were provided for electricity (\$/1000 Kilowatt hours), natural gas (\$/FT^3), and distillate fuel oil (\$/barrel).
- Prices are based on 1975 dollars for years 1975 through 1980.
- Prices were given for residential, commercial and industrial for each of the three fuel types.

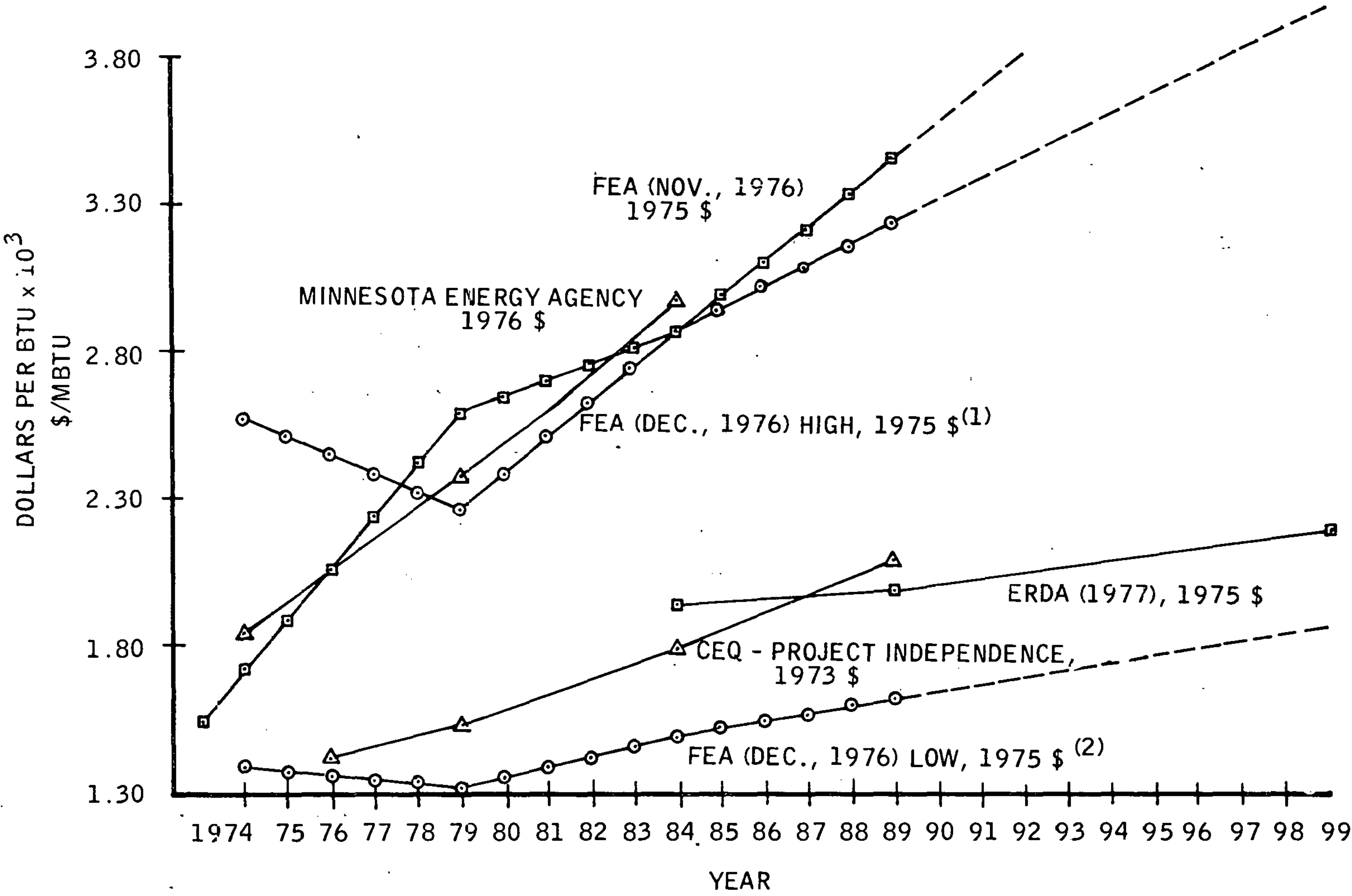
Two adjustments to the fuel prices were made. They were extrapolated through the year 1995 and converted to 1976 dollars by escalating the prices 6 percent. Those fuel prices used in the analysis are illustrated in Figures C-4 through C-9. Tables C-1 through C-8 are listings of the prices utilized.



(1) THE HIGH PROJECTION IS FOR THE REGION WITH THE HIGHEST PROJECTED PRICES CHOSEN FROM AMONG 10 U.S. GEOGRAPHICAL REGIONS.

(2) THE LOW PROJECTION IS FOR THE REGION WITH THE LOWEST PROJECTED PRICES CHOSEN FROM AMONG 10 U.S. GEOGRAPHICAL REGIONS.

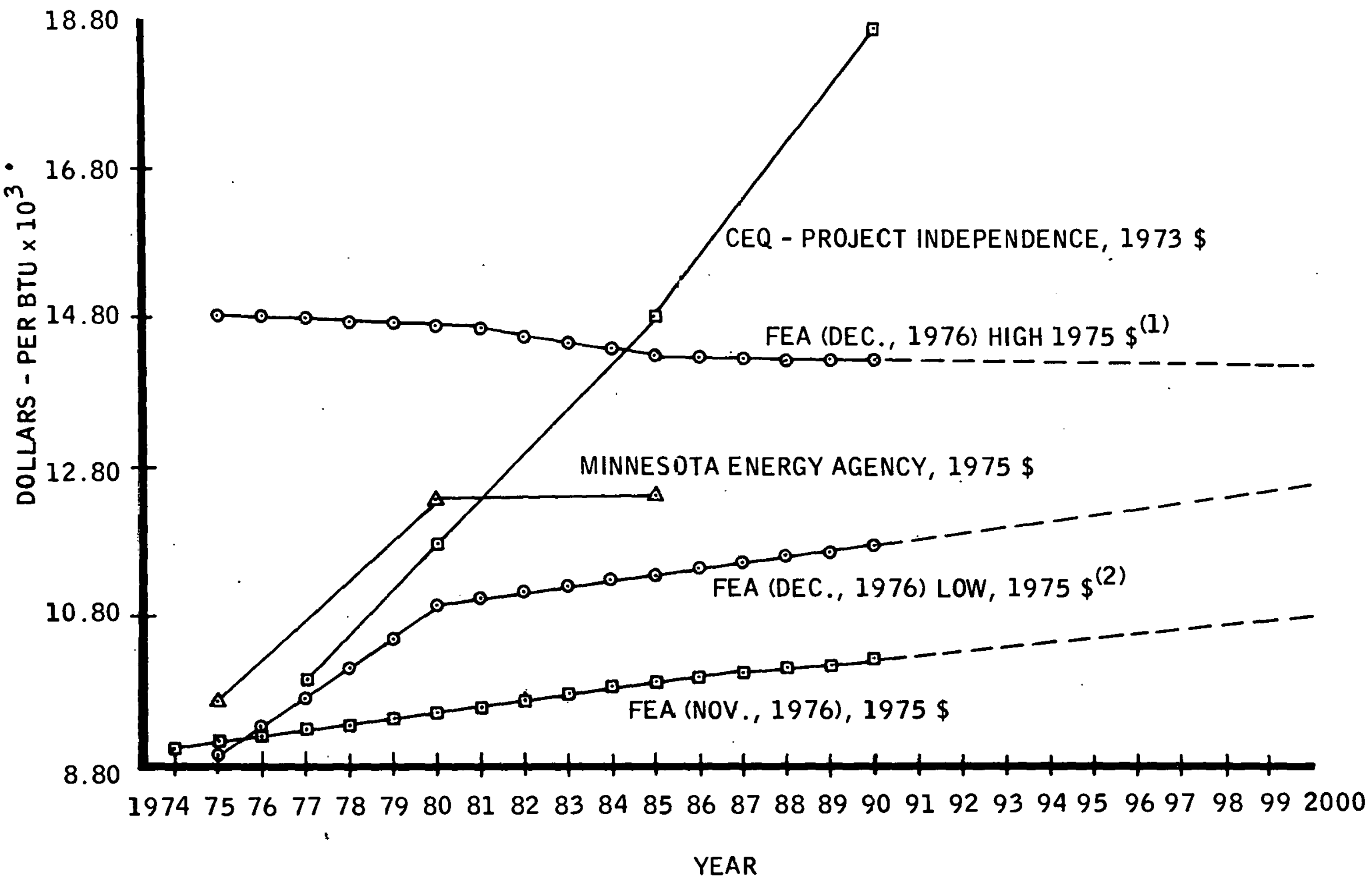
Figure C-1. Projected Oil Prices



(1) THE HIGH PROJECTION IS FOR THE REGION WITH THE HIGHEST PROJECTED PRICES, CHOSEN FROM AMONG 10 U. S. GEOGRAPHICAL REGIONS.

(2) THE LOW PROJECTION IS FOR THE REGION WITH THE LOWEST PROJECTED PRICES, CHOSEN FROM AMONG 10 U. S. GEOGRAPHICAL REGIONS.

Figure C-2. Projected Natural Gas Prices



(1) THE HIGH PROJECTION IS FOR THE REGION WITH THE HIGHEST PROJECTED PRICES, CHOSEN FROM AMONG 10 U. S. GEOGRAPHICAL REGIONS.

(2) THE LOW PROJECTION IS FOR THE REGION WITH THE LOWEST PROJECTED PRICES, CHOSEN FROM AMONG 10 U. S. GEOGRAPHICAL REGIONS.

Figure C-3. Projected Electricity Prices

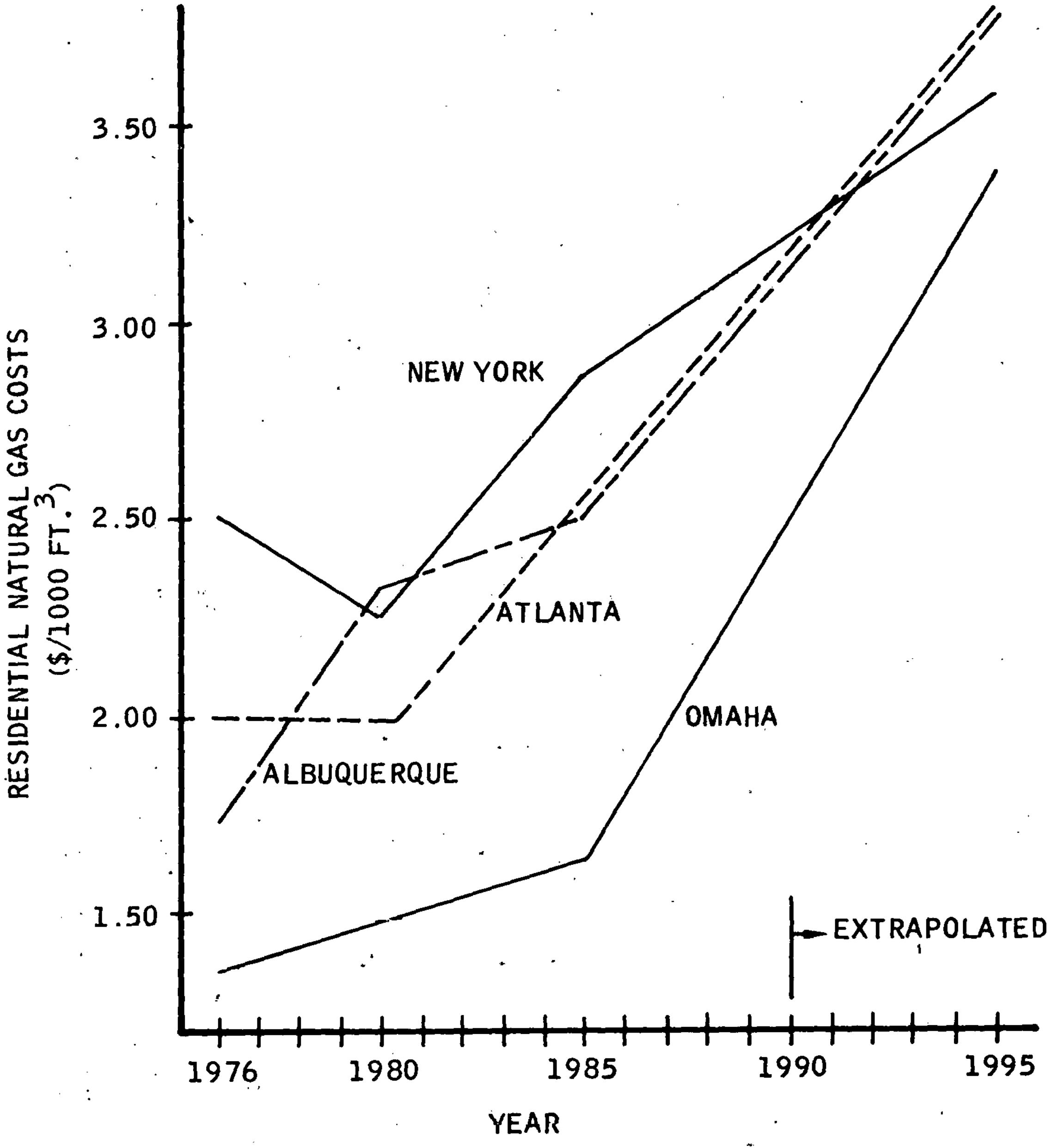


Figure C-4. Source: FEA 12/30/76; 1975 Dollars

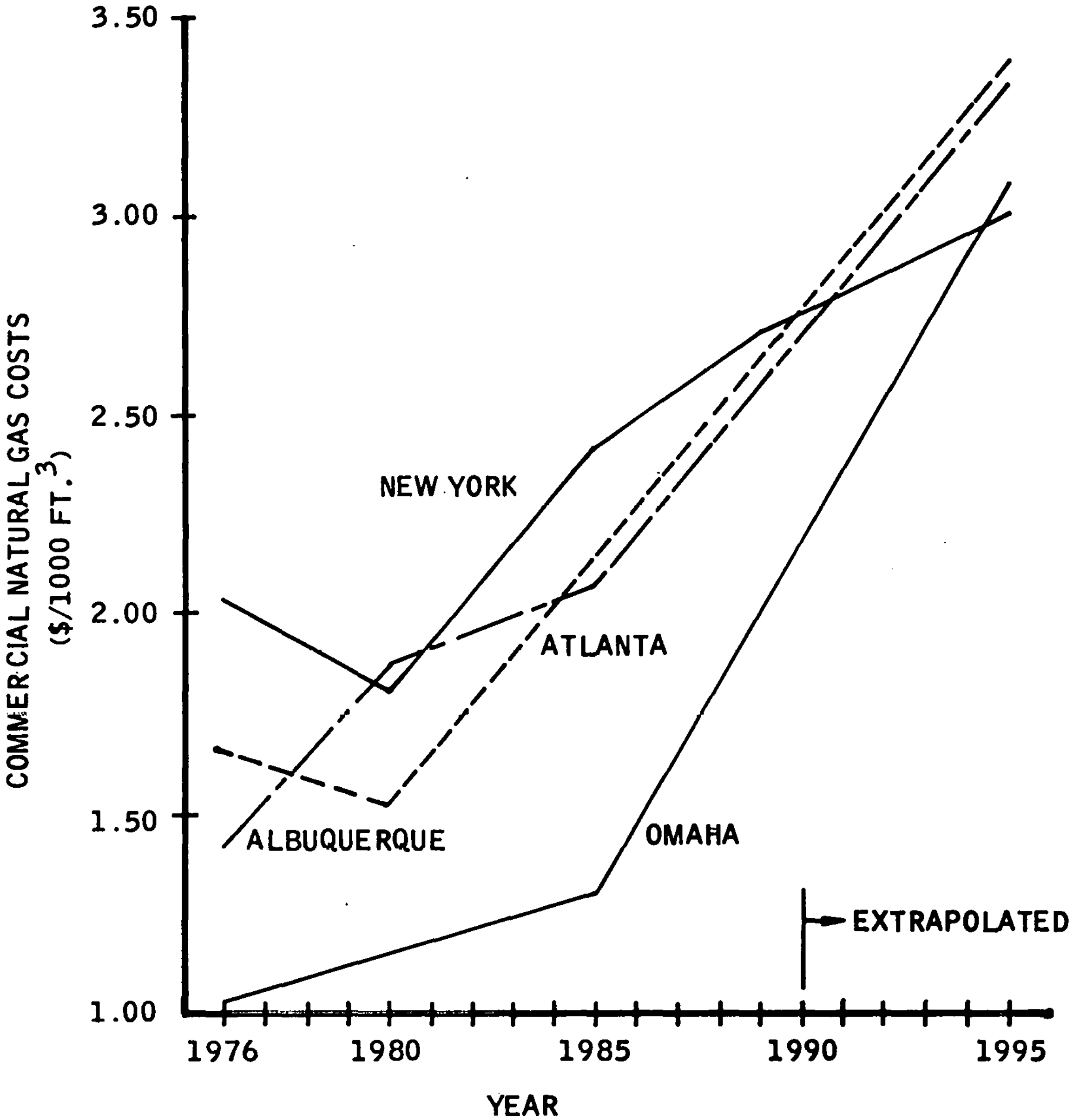


Figure C-5. Source: FEA: 12/30/76; 1975 Dollars

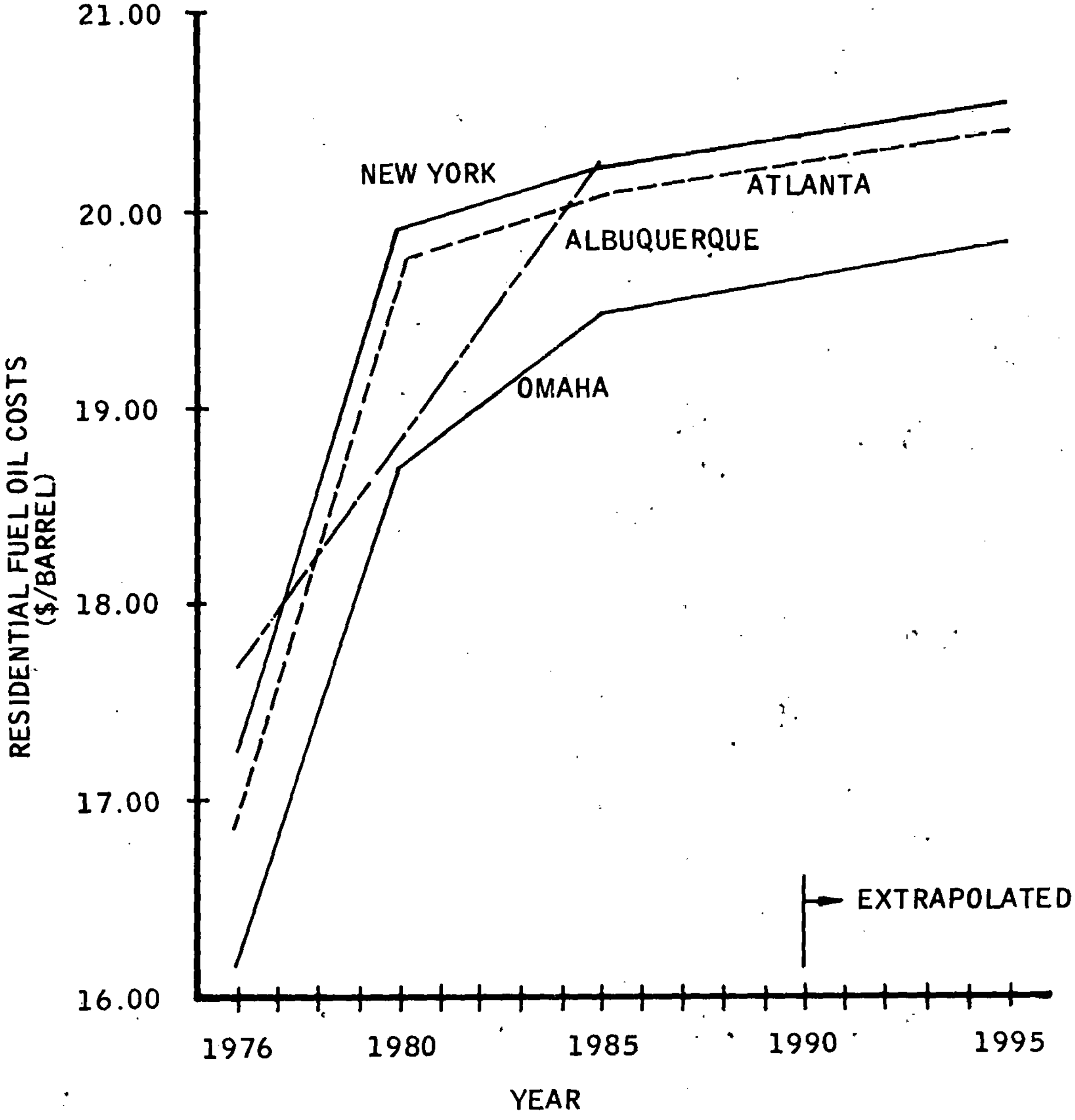


Figure C-6. Source: FEA, 12/30/76; 1975 Dollars

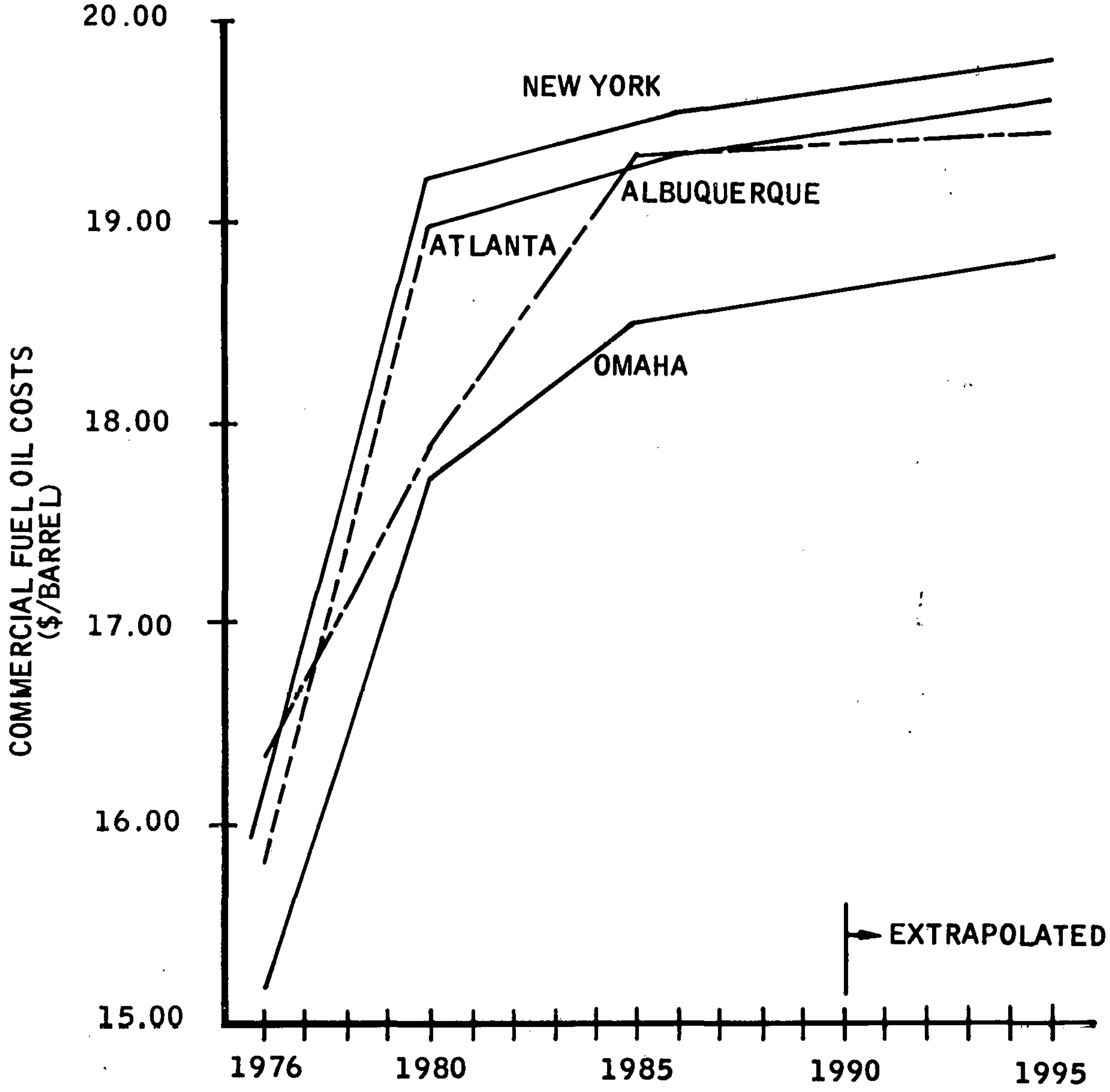


Figure C-7. Source: FEA 12/30/76; 1975 Dollars

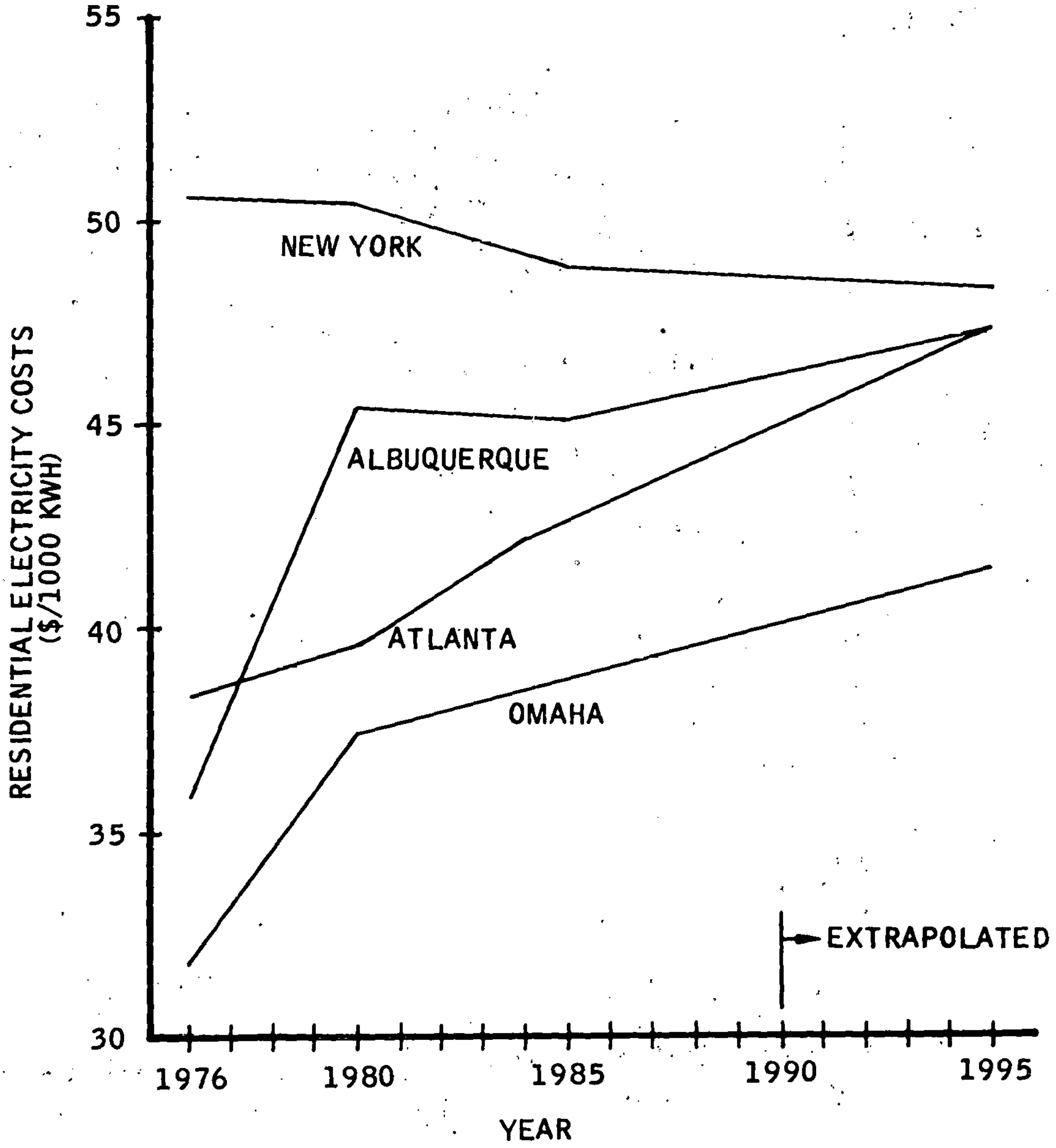


Figure C-8. Source: FEA: 12/30/76; 1975 Dollars

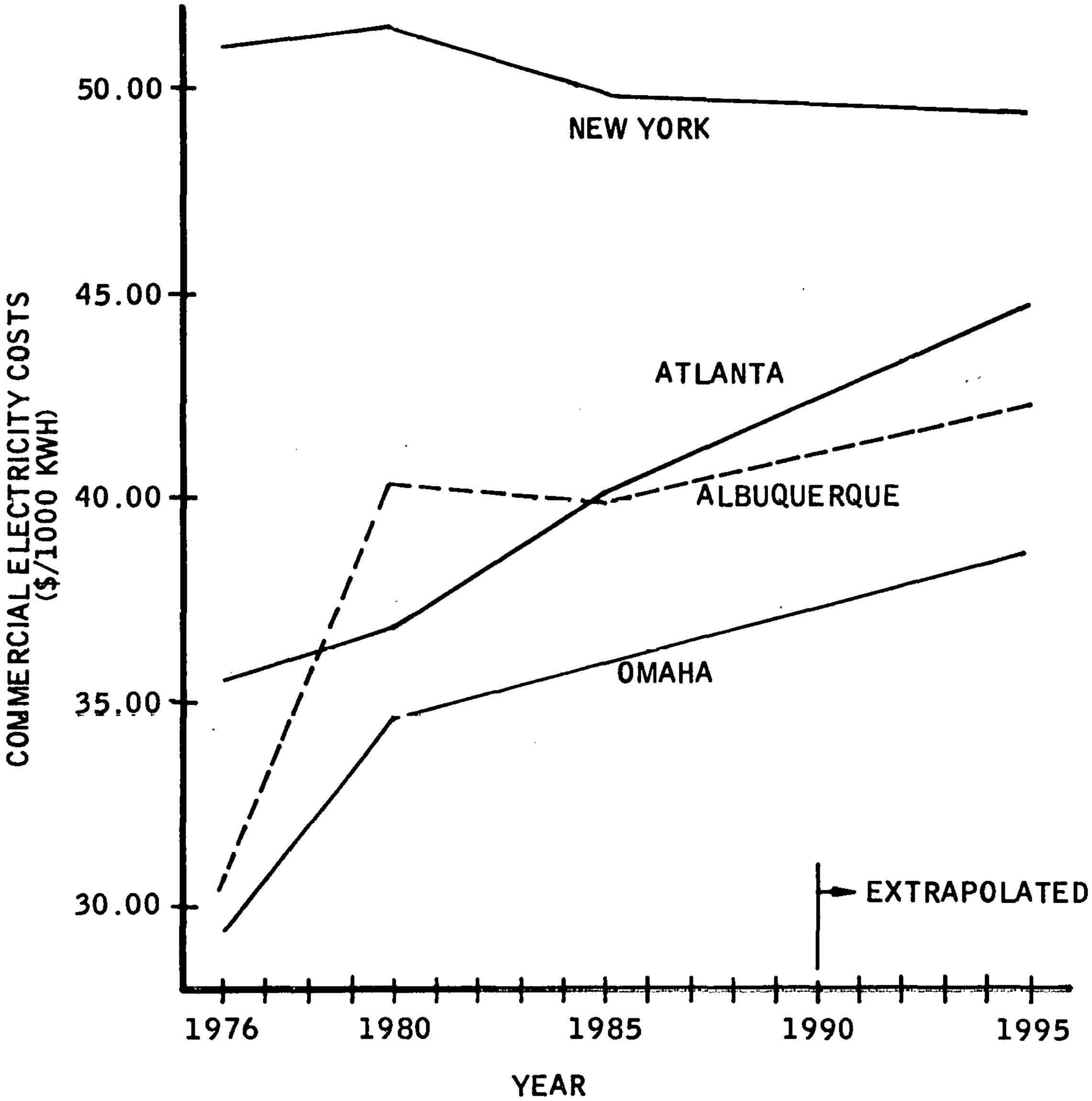


Figure C-9. Source: FEA, 12/30/76; 1975 Dollars

Table C-1. Residential Fuel Prices - New York

1976 Dollars

	Electricity	Natural Gas	Fuel Oil
0001976	53.61	2.66	18.31
0001977	53.56	2.60	19.01
0001978	53.51	2.52	19.93
0001979	53.46	2.46	20.42
0001980	53.40	2.40	21.13
0001981	53.08	2.52	21.19
0001982	52.77	2.65	21.25
0001983	52.45	2.78	21.31
0001984	52.13	2.90	21.37
0001985	51.81	3.04	21.43
0001986	51.76	3.12	21.47
0001987	51.70	3.19	21.50
0001988	51.64	3.26	21.54
0001989	51.59	3.34	21.57
0001990	51.54	3.42	21.60
0001991	51.48	3.50	21.65
0001992	51.43	3.57	21.68
0001993	51.38	3.65	21.71
0001994	51.33	3.72	21.74
0001995	51.27	3.79	21.77

Table C-2. Commercial Fuel Prices - New York

1976 Dollars

	Electricity	Natural Gas	Fuel Oil
0001976	54.06	2.16	16.86
0001977	54.16	2.10	17.74
0001978	54.25	2.04	18.62
0001979	54.35	1.98	19.49
0001980	54.44	1.92	20.37
0001981	54.12	2.05	20.44
0001982	53.81	2.18	20.50
0001983	53.49	2.31	20.55
0001984	53.17	2.44	20.62
0001985	52.85	2.57	20.68
0001986	52.80	2.64	20.71
0001987	52.74	2.72	20.74
0001988	52.68	2.80	20.79
0001989	52.63	2.87	20.82
0001990	52.58	2.93	20.85
0001991	52.52	2.98	20.89
0001992	52.47	3.03	20.92
0001993	52.42	3.08	20.96
0001994	52.36	3.14	20.99
0001995	52.31	3.19	21.02

Table C-3. Residential Fuel Prices - Omaha

1976 Dollars

	Electricity	Natural Gas	Fuel Oil
0001976	33.69	1.44	17.15
0001977	35.19	1.47	17.83
0001978	36.69	1.51	18.50
0001979	38.19	1.53	19.16
0001980	39.69	1.56	19.83
0001981	39.98	1.60	19.99
0001982	40.27	1.63	20.16
0001983	40.57	1.67	20.32
0001984	40.85	1.71	20.49
0001985	41.14	1.74	20.65
0001986	41.42	1.93	20.69
0001987	41.70	2.12	20.72
0001988	41.98	2.31	20.77
0001989	42.25	2.50	20.80
0001990	42.53	2.68	20.84
0001991	42.80	2.86	20.87
0001992	43.08	3.04	20.91
0001993	43.35	3.22	20.95
0001994	43.63	3.40	20.99
0001995	43.91	3.58	21.02

Table C-4. Commercial Fuel Prices - Omaha

1976 Dollars

	Electricity	Natural Gas	Fuel Oil
0001976	31.25	1.09	16.10
0001977	32.63	1.11	16.78
0001978	34.00	1.14	17.45
0001979	35.38	1.17	18.12
0001980	36.75	1.20	18.78
0001981	37.05	1.23	18.94
0001982	37.33	1.27	19.11
0001983	37.63	1.30	19.27
0001984	37.92	1.35	19.44
0001985	38.20	1.38	19.60
0001986	38.49	1.57	19.64
0001987	38.76	1.76	19.67
0001988	39.04	1.94	19.72
0001989	39.32	2.13	19.75
0001990	39.59	2.32	19.79
0001991	39.87	2.51	19.82
0001992	40.14	2.70	19.86
0001993	40.31	2.89	19.90
0001994	40.59	3.08	19.93
0001995	40.86	3.28	19.96

Table C-5. Residential Fuel Prices - Atlanta

1976 Dollars

	Electricity	Natural Gas	Fuel Oil
0001976	40.60	2.10	17.91
0001977	40.94	2.09	18.68
0001978	41.28	2.07	19.43
0001979	41.62	2.06	20.18
0001980	41.97	2.05	20.93
0001981	42.63	2.18	21.01
0001982	43.30	2.31	21.07
0001983	43.98	2.45	21.15
0001984	44.65	2.59	21.21
0001985	45.33	2.71	21.28
0001986	45.81	2.85	21.32
0001987	46.30	2.98	21.35
0001988	46.80	3.11	21.39
0001989	47.29	3.24	21.42
0001990	47.78	3.37	21.45
0001991	48.27	3.50	21.50
0001992	48.77	3.64	21.53
0001993	49.27	3.76	21.56
0001994	49.76	3.89	21.60
0001995	50.24	4.03	21.63

Table C-6. Commercial Fuel Prices - Atlanta

1976 Dollars

	Electricity	Natural Gas	Fuel Oil
0001976	37.76	1.75	16.77
0001977	38.09	1.73	17.61
0001978	38.43	1.69	18.43
0001979	38.75	1.64	19.27
0001980	39.08	1.61	20.11
0001981	39.75	1.74	20.18
0001982	40.42	1.88	20.25
0001983	41.10	2.01	20.32
0001984	41.76	2.14	20.38
0001985	42.44	2.28	20.46
0001986	42.93	2.41	20.49
0001987	43.42	2.54	20.52
0001988	43.92	2.67	20.56
0001989	44.40	2.80	20.60
0001990	44.90	2.94	20.63
0001991	45.39	3.06	20.67
0001992	45.89	3.20	20.70
0001993	46.39	3.33	20.73
0001994	46.87	3.46	20.78
0001995	47.37	3.59	20.81

Table C-7. Residential Fuel Prices - Albuquerque

1976 Dollars

	Electricity	Natural Gas	Fuel Oil
0001976	38.14	1.83	18.75
0001977	40.65	1.98	19.03
0001978	43.16	2.14	19.31
0001979	45.68	2.30	19.60
0001980	48.20	2.46	19.89
0001981	48.10	2.50	20.20
0001982	48.02	2.54	20.51
0001983	47.92	2.59	20.83
0001984	47.84	2.62	21.14
0001985	47.75	2.66	21.45
0001986	47.99	2.80	21.47
0001987	48.23	2.93	21.49
0001988	48.47	3.06	21.50
0001989	48.72	3.20	21.52
0001990	48.96	3.33	21.53
0001991	49.21	3.47	21.55
0001992	49.45	3.60	21.56
0001993	49.69	3.73	21.58
0001994	49.94	3.87	21.59
0001995	50.18	4.01	21.61

Table C-8. Commercial Fuel Prices - Albuquerque

1976 Dollars

	Electricity	Natural Gas	Fuel Oil
0001976	32.53	1.49	17.32
0001977	35.08	1.62	17.71
0001978	37.63	1.75	18.12
0001979	40.17	1.87	18.51
0001980	42.73	1.99	18.91
0001981	42.63	2.04	19.23
0001982	42.55	2.08	19.54
0001983	42.45	2.12	19.85
0001984	42.37	2.16	20.16
0001985	42.28	2.19	20.48
0001986	42.52	2.33	20.49
0001987	42.76	2.47	20.51
0001988	43.00	2.60	20.52
0001989	43.25	2.73	20.54
0001990	43.49	2.86	20.55
0001991	43.74	3.00	20.57
0001992	43.98	3.13	20.59
0001993	44.22	3.26	20.61
0001994	44.47	3.39	20.62
0001995	44.71	3.53	20.64

APPENDIX D
LIFE CYCLE COST MODEL

The mixed strategies analysis examines the interaction of energy conservation techniques and solar heating/cooling systems in typical buildings. To assess and measure the economic interaction, a life cycle cost model was developed to evaluate and compare the economics of a solar heated/cooled building and various combinations of energy conservation techniques. The model * (Table D-1) accounts for the changing real value of money over time. Present value costs are determined over the period of analysis and then divided into uniform annual costs by discounting. The model assumes that the system is purchased completely with equity funds (cash) and is not depreciated. Discount rates are expressed in real terms (net of inflation) rather than nominal terms (rates that include inflation).

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* Ruegg, Rosalie T., Solar Heating and Cooling in Buildings: Methods of Economic Evaluation, NBSIR 74-712, National Bureau of Standards, July 1975.

Table D-1 Life Cycle Annual Cost Model

Cost Item	Definition
$AC = CRF \Big\{$	Capital recovery factor to convert present value costs to annual costs
$+ I_s$	Installed cost of solar system
$- \frac{S_s}{(1+i)^N}$	Salvage value exclusive of removal and disposal
$+ M_s \sum_{j=1}^{N} \left(\frac{i+e_m}{1+i}\right)$	Maintenance, repair and replacement of solar system
$+ O_s \sum_{j=1}^{N} \frac{E_j}{(1+i)^j}$	Operating costs for solar system, pumps, fans
$+ O_{AK} \sum_{j=1}^{N} \frac{F_{jK}}{(1+i)^j}$	Operating costs for auxiliary fuels for heating, hot water and air conditioning
$+ INS_s \sum_{j=1}^{N} \left(\frac{1+e_{INS}}{1+i}\right)^j$	Insurance
$+ I_E$	Installed cost of energy conservation technique
$- \frac{S_E}{(1+i)^N}$	Salvage value of energy conservation technique

Table D-1 Life Cycle Annual Cost Model (Concluded)

Cost Item	Definition
$+ M_E \sum_{j=1}^{N} \left(\frac{1+e_E}{1+i}\right)^j$	Maintenance, repair and replacement of energy conservation technique
$+ O_E \sum_{j=1}^{N} \frac{E_j}{(1+i)^j}$	Operating costs of energy conservation technique
$+ INS_E \sum_{j=1}^{N} \left(\frac{1+e_{INS}}{1+i}\right)^j$	Insurance costs

where

AC = Annual cost of solar heating/cooling system and energy conservation technique over period of analysis.

N = Period of analysis

CRF = Capital recovery factor

i = Annual real discount rate

I_s = Installed cost of solar system

S_s = Savlage value of solar system exclusive of removal and disposal

M_s = Maintenance rate of solar system

e_m = Escalation of maintenance rate

O_s = Operating cost of solar system components over one year period

E_j = Yearly cost of operating fuel (electricity for pumps and fans) for solar system components

O_{AK} = Operating cost of auxiliary heating system with fuel type K

F_{jK} = Yearly cost of fuel for electricity, natural gas or fuel oil

INS_s = Insurance rate on solar system

e_{INS} = Insurance Escalation rate

I_E, S_E, M_E, e_E, O_E, INS_E, e_{INS}

= Terms similar to those of solar system, but applied to costs, rates and escalations of energy conservation techniques.

Cost Components

Installed Cost of System -- Installed costs include costs for solar heating/cooling system, domestic hot water, auxiliary furnace system, and Energy Conservation Techniques (ECTs). Cost components of the solar system are described in detail in Appendix F; those of the Energy Conservation Techniques in Appendix B.

Salvage Value -- Salvage value describes the value of the solar heating/cooling system and ECT at the end of the period of analysis. Salvage value is exclusive of removal and disposal costs.

Maintenance -- Maintenance costs are expressed as a precentage of the value of the Solar System or ECT.

Insurance -- Property insurance costs are expressed as a precentage of the value of the Solar System and ECT.

Operating -- Operating costs of the Solar System or ECT refers to the yearly cost of electricity necessary to operate the pumps, fans, etc.

Auxiliary Heating, Hot Water and Air Conditioning -- Auxiliary heating costs include the cost of fuel to provide the auxiliary loads for space heating and domestic hot water. Auxiliary costs for electricity, natural gas and fuel oil are provided using forecasted fuel prices.

Cost Components Not Considered

Building Space -- Building space occupied by HVAC System components (expressed as building costs/ft^2 times the number of ft^2 occupied) is sometimes considered as a term in the life cycle cost model. If incorporated into the mixed strategies analysis, it would tend to increase life cycle costs because of the space occupied by storage; which was considered as internal to new building types analyzed. The tank will probably use 1/2 percent or less of the floor space and was felt to be negligible in this study.

Property Tax -- Property taxes are assessed as a percentage of the market value of the building; A building with a solar heating/cooling system would have a higher valuation and thus higher property taxes as compared to a building with a conventional HVAC system. Life cycle costs would tend to increase. The amount of increase is dependent on local property tax rates, property assessment practices and the income tax bracket of the building owner/operator. Also, some states have passed laws to not tax solar. Because this is such a local issue it was deemed best to ignore this cost here.

Government Incentives -- Government incentives include those programs designed to encourage widespread usage of solar systems, which would tend to decrease life cycle costs. These include the following:

- Property Tax Relief -- Solar systems would be partially or totally excluded from property tax assessments.
- Tax Credit -- A direct tax credit to the purchaser or the solar system.
- Low Interest Loans -- Below market interest rates to purchasers of solar systems.
- Grant to Manufacturers/Buyer -- A direct grant or subsidy to manufacturer or purchaser of a solar system.
- Surcharge on Energy Usage -- Taxing conventional fuels and HVAC systems at a higher rate to discourage usage.

It will probably require incentives to make solar systems cost effective to the building owner.

Economic Model Assumptions

Assumptions used in the economic analysis for each of the five building types are specified in Table D-2. Additional clarification of some assumptions includes:

Period of Analysis -- The period of analysis was selected as a 20 year period beginning in 1976. The length of the period is arbitrary and is primarily related to the validity of estimations for future fuel prices and expected lifetimes of the solar system components.

Discount Rates -- A real discount rate of 2 percent was selected for the analysis. Discount rates can be expressed in real terms (net of inflation) or nominal (market rates that include inflation) rates. Either method can be used as long as all costs are discounted in similar terms.

Insurance Rates -- Insurance rates vary significantly with respect to building types, age and valuation of building and contents. A rate of 0.004 to 0.006 was selected as representative of current insurance rates for the building types analyzed.

Table D-2. Economic Analysis Assumptions

MIXED STRATEGIES ANALYSIS

	S.F. New	S. F. Existing	MF New	MF Existing	RS New	RS Existing	OB New	OB Existing	School New	School Existing
SYSTEM COST										
Salvage Rate	.10	.10	.10	.10	.10	.10	.10	.10	.10	.10
Maintenance Rate	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
Insurance Rate	.004	.004	.004	.004	.006	.006	.006	.006	.005	.005
Period of Analysis	20	20	20	20	20	20	20	20	20	20
Real Discount Rate	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
ECT COST										
Salvage Rate	0 or .1	0 or .1	0 or .1	0 or .1	0 or .1	0 or .1	0 or .1	0 or .1	0 or .1	0 or .1
Maintenance Rate	0 or .01	0 or .01	0 or .01	0 or .01	0 or .01	0 or .0	0 or .01	0 or .01	0 or .01	0 or .01

APPENDIX E
SIMULATION MODELS

The material presented in this appendix consists of detailed descriptions of the two simulation models DYNSIM and SUNSIM, that were used for this study. Included in the descriptions are the modeling assumptions as well as the means by which the building loads were determined.

SUNSIM MODEL DESCRIPTION

The SUNSIM model is a static simulation of a house equipped with a solar heating, cooling and hot water system. The schematic for this model is described in Figure E-1. It consists of a collector field, collector piping loop, a secondary pipe loop connected to storage, a heating system, and a Rankine cycle air conditioner.

The computational procedure for this model is based on the instantaneous energy balance of the house rather than its dynamical responses. This procedure may not describe the response of the air mass in the house well, but for a small air mass, we can assume that it responds immediately to the input temperature. The advantage of this procedure is that we can use the concept of time fractions for various modes of heating or cooling spent in each integration step, thus, allowing large integration steps.

The remainder of this section describes the mathematical structure of the house model, the logic of control modes, and documents a glossary for the SUNSIM package.

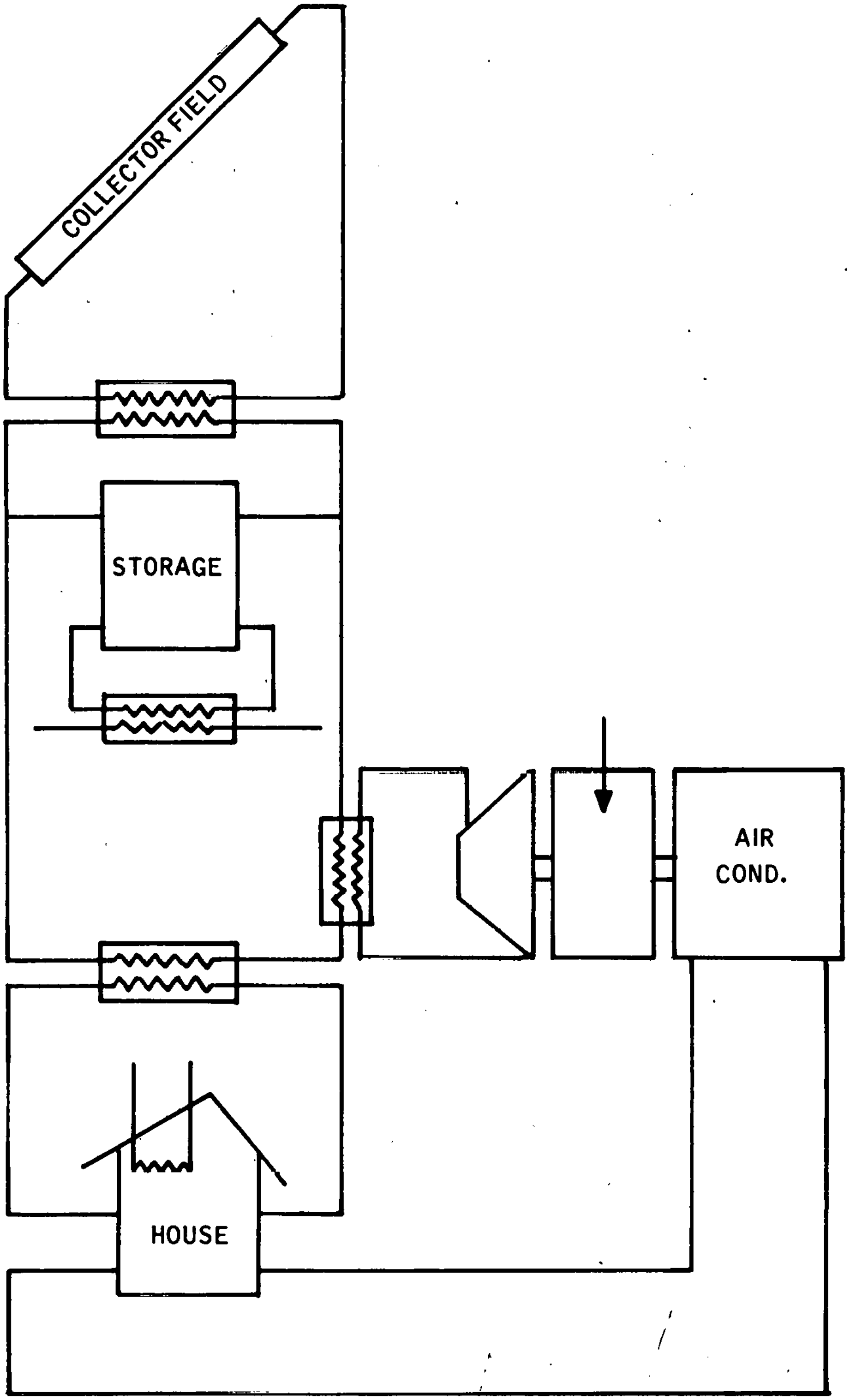


Figure E-1. Schematic Diagram of a Solar House Model Equipped with a HVAC System.

Nomenclature

A_c	Collector area, ft^2
A_h	Envelope roof and wall area of house, ft^2
A_s	Storage wall area, ft^2
c_{air}	Thermal capacity
c_c	Thermal capacity of fluid in collector loop, BTU/lb °F
c_s	Thermal capacity of fluid in storage loop, BTU/lb °F
c_w	Thermal capacity of water, BTU/lb °F
D_p	Diameter of collector loop pipes, ft
I	Insolation strength, BTU/ft^2hr
L_p	Length of collector loop pipes, ft
$\dot{m}_c$	Mass flow rate of collector loop fluid, lb/hr
$\dot{m}_s$	Mass of the storage fluid, lbs
q_{aux}	Auxiliary energy required by the system, BTU/hr
q_f	Energy furnished to the house, BTU/hr
q_h	Load of the house, BTU/hr
q_{hotw}	Solar energy supply for domestic hot water, BTU/hr
q_{ℓ}	Energy loss from storage to house, BTU/hr
q_{solar}	Solar energy required for Rankine cycle turbine, BTU/hr
T_{amb}	Ambient air temperature, °F
T_h	Temperature of the house, °F
T_{hotw}	Domestic hot water temperature, °F
T_i	Collector inlet temperature, °F
$T_{\ell 1}$	Storage loop temperature, °F
$T_{\ell 2}$	Storage loop temperature, °F
$T_{\ell 3}$	Storage loop temperature, °F
$T_{\ell 4}$	Storage loop temperature, °F
T_o	Collector outlet temperature, °F
T_s	Storage temperature, °F
T_{well}	Well water temperature, °F
T_1	Collector loop temperature, °F

T_4	Collector loop temperature, °F
U_h	Heat transfer coefficient of house wall, BTU/ft^2 °F hr
U_p	Heat transfer coefficient of collector loop pipes, BTU/ft^2 °F hr
U_s	Heat transfer coefficient of storage wall, BTU/ft^2 °F hr
ϵ_1	Effectiveness of heat exchanger between collector and storage
ϵ_2	Effectiveness of heat exchanger between storage and house
ϵ_w	Effectiveness of heat exchanger for domestic hot water
η_c	Collector efficiency
ρ_{air}	Density of air, lb/ft^3

General Control Logic

Basically, a HVAC equipped solar house is operated in the following modes, depending on the weather condition and the house load:

Mode 1: Shut Down -- The solar house system is shut down; no auxiliary heating or auxiliary chilling is allowed in this mode.

Mode 2: Direct Solar Heating -- The house is heated directly from solar heat collected from solar collectors.

Mode 3: Heating from Storage -- The house is heated indirectly from solar heat stored in storage.

Mode 4: Charging Storage -- The excess of solar energy after furnishing the house load is charged to storage for use when necessary.

Mode 5: Purging -- Whenever the storage temperature is close to the boiling point of the medium fluid in the storage, a purge is used to throw away the excess collected energy.

Mode 6: Direct Cooling -- The house is cooled from the chiller with energy furnished directly from collectors.

Mode 7: Cooling from Storage -- The house is cooled from the chiller with solar energy furnished from storage. The auxiliary heater or auxiliary chiller is turned on at any mode to satisfy the house load anytime the solar energy supply is insufficient. The mode switch conditions and computational procedure for each mode will be detailed in a later section.

Mode 8: Sole Auxiliary Heating -- Only the auxiliary heating unit is operating in this mode.

Mode 9: Sole Auxiliary Cooling -- Only the auxiliary cooling unit is operating in this mode.

Computing Equations

(1) Solar Heat Collection -- The solar heat is collected from the collector field. The collector efficiency determines the amount of heat collection:

$$q_c = \eta_c A_c I = \acute{m}_c c_c (T_0 - T_i)$$

(2) Piping Losses -- The losses of the pipelines from house to collector field and from the field back are computed as follows:

$$(T_1 - T_{amb}) = (T_o - T_{amb})\, e^{-\mu_1}$$

$$(T_i - T_{amb}) = (T_4 - T_{amb})\, e^{-\mu_2}$$

where: $\mu_i = \dfrac{U_p \pi D_p L_{pi}}{m_c c_c}, \quad i = 1, 2$

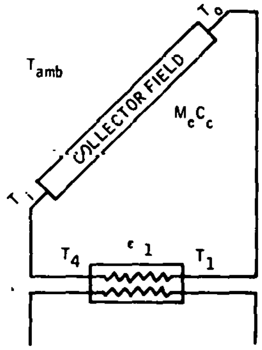


Figure E-2. Collector Loop

(3) Heat Exchangers -- There are three heat exchangers in the storage loop and one in the comestic hot water subsystem. The one with the effectiveness ϵ_{ac} is assumed to be part of the chiller subsystem and not computed here. The equations for the effectiveness are:

$$\epsilon_1 = \frac{\acute{m}_c c_c}{(\acute{m}c)_{min}} \; \frac{(T_1 - T_4)}{(T_1 - T_{\ell_1})}$$

$$\epsilon_2 = \frac{\acute{m}_s c_s}{(\acute{m}c)_{min}} \; \frac{(T\ell_3 - T\ell_4)}{(T\ell_3 - T_h)}$$

$$\epsilon_w = \frac{\acute{m}_w c_w}{(\acute{m}c)_{min}} \; \frac{(T_{hotw} - T_{well})}{(T_s - T_{well})}$$

where $(\dot{m}c)_{min}$ is the minimum of the two flow rates in a heat exchanger.

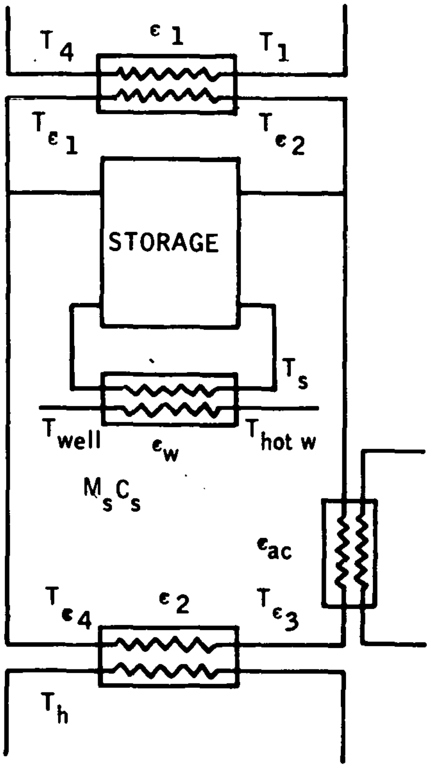


Figure E-3. System Heat Exchangers

(4). House Load -- The house load depends on the difference of house and ambient temperatures, the CFM of ventilating air, and the humidity of air. The heat loss through the house wall is:

$$q_1 = U_h A_h (T_h - T_{amb})$$

CFM of ventilating air contributes a load of:

$$q_2 = \rho_{air} c_{air} (60 \times CFM) (T_h - T_{amb})$$

$$\approx 1.08 (CFM) (T_h - T_{amb})$$

For air conditioning, the dehumidifying process in the house imposes a load equal to:

$$q_3 = \rho_{air} (60 \times CFM)(w_{amb} - w_h)(h_w)$$

$h_w = h_{fg} + h_{\Delta T}$

h_{fg} = latent heat of water at normal conditions

$h_{\Delta T}$ = heat needed to raise saturated vapor at normal conditions to some desired temperature.

w_{amb} = specific humidity of amient air

w_h = specific humidity of house air

The total heating or cooling load of the house is then:

$$q_h = q_1 + q_2 + q_3 + q_4$$

where q_4 is the extra people, lighting, etc., load.

(5) Energy Balance in House -- Without considering the dynamical response of the air mass, the energy balance in the house is:

$$q_h + q_f + q_{aux} = 0$$

where q_f is the heating or cooling BTU furnished to the house by solar energy.

(a) For heating,

$$q_f = \dot{m}_s c_s (T_{\ell 3} - T_{\ell_4})$$

(b) For cooling, the solar heat supplied to the Rankine turbine is:

$$q_{solar} = \dot{m}_s c_s (T_{\ell_2} - T_{\ell_3}) \qquad \text{and,}$$

$$q_f = \eta_t \, COP \, q_{solar} = COP \, q_t$$

where η_t is the turbine efficiency COP is the air conditioner coefficient of performance. q_t is the turbine power output. η_t and q_t are functions of inlet temperature T_{ℓ_2} .

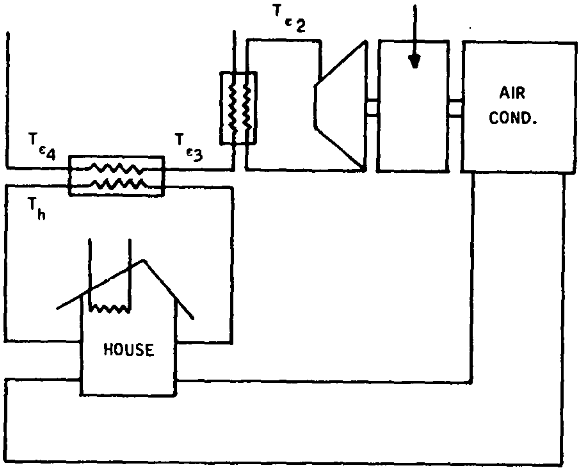


Figure E-4. Heating and Cooling Subsystem in House

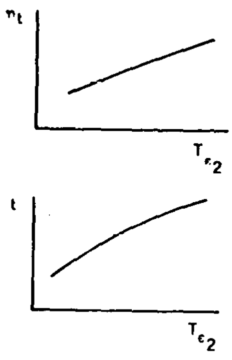


Figure E-5. η_t and COP as functions of inlet temperature

(6) Energy Balance in Storage -- The equation for energy balance for storage can be written as follws:

$m_s c_s \frac{dT_s}{dt} = q_\ell + q_t - q_{hotw}$ where,

$q_\ell = V_s A_s (T_s - T_h)$: loss from storage to house.

$q_t = m'_c c_c (T_1 - T_4)$: solar heat charged from collector.

or, $q_t = m'_s c_s (T_{\ell_3} - T_{\ell_4})$: heat supply to the house for heating.

or, $q_t = \eta_t \, COP \, q_{solar}$: heat supply to the house for cooling.

$q_{hotw} = m'_w c_w (T_{hotw} - T_{well})$: domestic hot water supply.

Constraints and Computations In Each Mode

Each mode is limited by some certain constraints and, thus, the computational procedure for each mode is somewhat different.

Mode 1: Shut Down -- When the load of the house is zero, no auxiliary heating or cooling is allowed in this mode. Energy balance in the house is:

$$q_h = 0$$

Domestic hot water is computed from:

$$T_{hotw} = T_{well} + \epsilon_w \frac{(m'c)_{min_{hotw}}}{m'_w \; c_w} (T_s - T_{well})$$

Thus, heat supply for hot water is:

$$q_{hotw} = m'_w \, c_w \, (T_{hotw} - T_{well})$$

Then, from the equation:

$$m_s c_s \frac{dTs}{dt} = -q_\ell - q_{hotw}$$

T_s is computed.

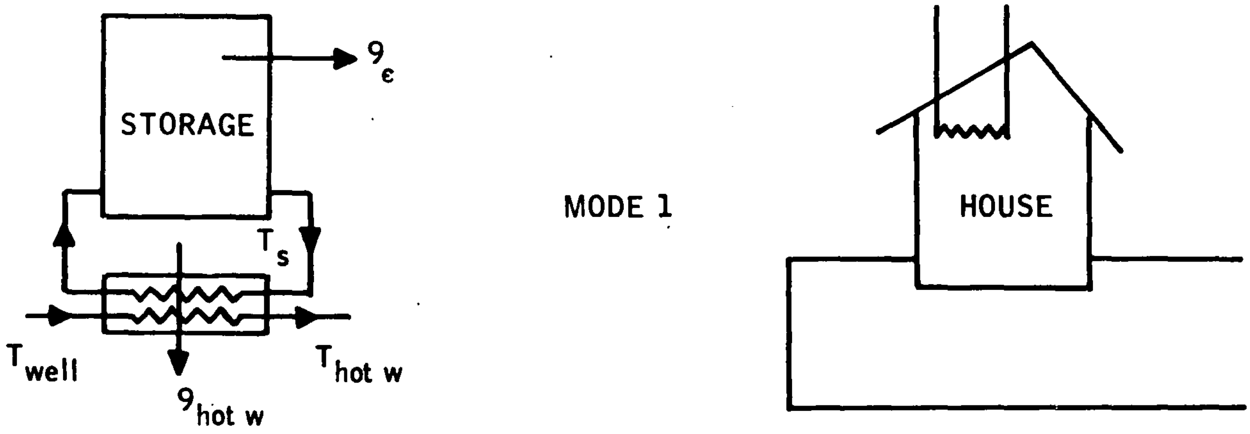


Figure E-6. Diagram for Mode 1

Mode 2: Direct Solar Heating -- If the house needs heating and there is a sufficient amount of sunshine, it can be heated directly from the collectors. From the diagram for Mode 2, the temperature of the collector loop and storage loop are not known. To find these temperatures, we have to iterate th loops for energy balance. Newton's (gradient) technique is found to be the most effectove method for this iteration.

Start with a guess for T_1 and T_{ℓ_1}. In the collector loop, T_4 is computed from:

$$T_4 = T_1 - (T_1 - T_{\ell_1})\ \varepsilon_1\ \frac{(\dot{m}c)_{1\ min}}{\dot{m}_c c_c}$$

then, $T_i = T_{amb} + (T_4 - T_{amb})\, e^{-\mu 2}$

with a certain amount of insolation, the temperature at the outlet of the collector is found from:

$$T_o = T_i + \frac{\eta_c A_c}{\dot{m}_c c_c} I .$$

The temperature at the inlet to the house is:

$$T'_1 = T_{amb} + (T_o - T_{amb})\, e^{-\mu 1}$$

In the storage loop, the amount of heat transferred through the heat exchanger 1:

$$q_{t_1} = \dot{m}_c c_c (T_1 - T_4)$$

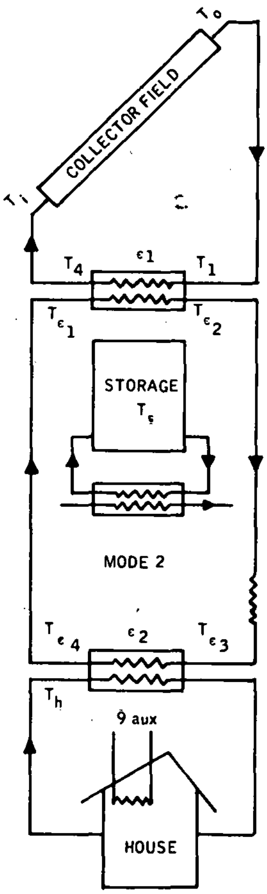


Figure E-7. Diagram for Mode 2

T_{ℓ_2} is computed from:

$$T_{\ell_2} = T_{\ell_1} + \frac{q_{t_1}}{\dot{m}_s c_s}$$

$T_{\ell_3} = T_{\ell_2}$, thus, T_{ℓ_4} is determined from:

$$T_{\ell_4} = T_{\ell_3} - (T_{\ell_3} - T_h)\, \epsilon_2 \, \frac{(\dot{m}c)_{2\,\min}}{\dot{m}_s c_s}$$

From the diagram, a new value for T_{ℓ_1} is:

$$T_{\ell_1}{}' = T_{\ell_4}$$

Compare T'_{ℓ} and T'_{ℓ_1} with T_1 and T_{ℓ_1} respectively. If $T_1 = T'_1 \pm \epsilon_1$ and $T_{\ell_1} = T'_{\ell_1} \pm \epsilon_2$, where ϵ_1 and ϵ_2 are the tolerable errors, then T_1 and T_{ℓ_1} are the right temperatures of the loops.

If not, compute the gradient of:

$Q_c = m_c c_c (T'_1 - T_1)$

$Q = m_s c_s (T'_{\ell_1} - T_{\ell_1})$

with respect to T_1 and T_{ℓ_1}

$$\text{Grad } Q = \begin{bmatrix} 2Q_c & 2Q_c \\ 2T_1 & 2T_{\ell_1} \\ 2Q & 2Q \\ 2T_1 & 2T_{\ell_1} \end{bmatrix}$$

From which, we can predict a new, better guess for T_1 and T_{ℓ_1} as follows:

$$\begin{Bmatrix} T_1 \\ T_{\ell_1} \end{Bmatrix} = \begin{Bmatrix} T_1 \\ T_{\ell_1} \end{Bmatrix} - \left[\text{Grad } Q\right]^{-1} \begin{Bmatrix} Q_c \\ Q_\ell \end{Bmatrix}$$

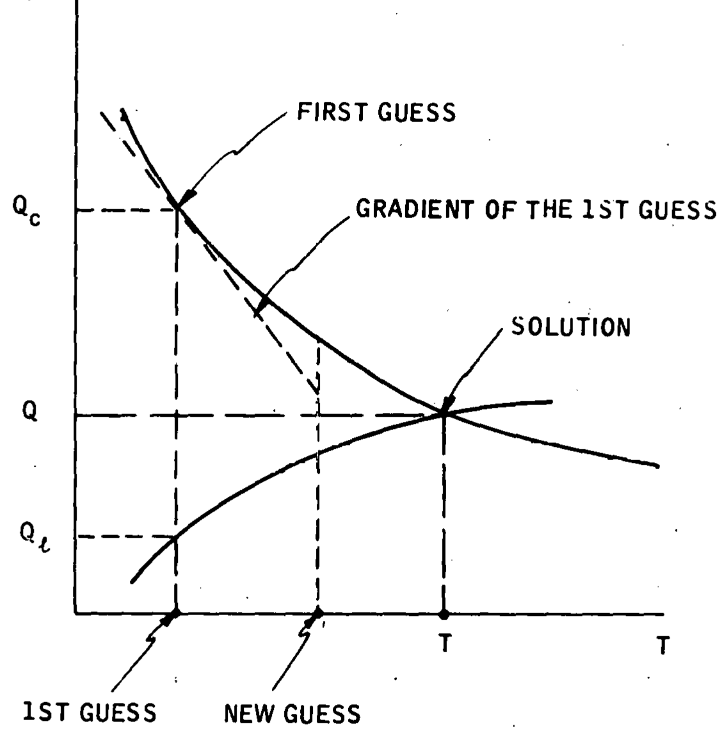


Figure E-8. Newton's Gradient Technique

Reiterate until the solution is found.

Knowing the right values of collector loop and storage loop temperatures, the heat transfer from the heat exchanger to the house is determined from:

$$q_f = m_c c_c (T_1 - T_4) = m_s c_s (T_{\ell_3} - T_{\ell_4})$$

And the energy balance in the house is:

$$q_h + q_f + q_{aux} = 0$$

From the energy balance equation for storage:

$$m_s c_s \frac{dTs}{dt} = -q_\ell - q_{hotw}$$

$\bar{T}_s$ is determined.

Mode 3: Heating from Storage -- If the house needs heat and there is not sufficient insolation, and if the storage temperature is high enough, heat the house from storage.

$T_{\ell_3} = T_s$

And, $T_{\ell_4} = T_{\ell_3} - (T_{\ell_3} - T_h)\ {}_2\ \frac{(mc)_{2min}}{m_s c_s}$

The heat transfer to the house is:

$$q_f = m_s c_s (T_{\ell_3} - T_{\ell_4})$$

Energy balance in the house is:

$$q_h + q_f + q_{aux} = 0$$

In the storage,

$$m_s c_s \frac{dTs}{dt} = -q_\ell - q_f - q_{hotw}$$

From that equation, T_s is determined.

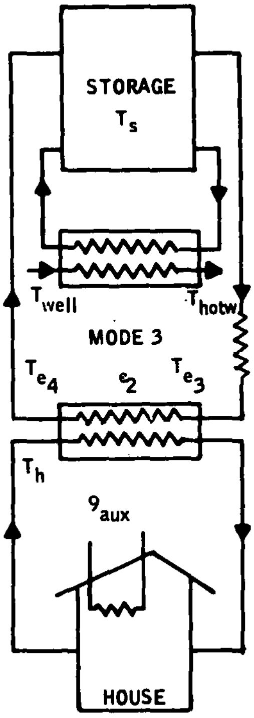


Figure E-9
Diagram for Mode 3.

Mode 4: Charging Storage -- If there is insolation and the house does not need heating or cooling, and if the storage temperature does not reach boiling point, charge the storage with collected energy. The computational procedure for this mode involved a one loop (first degree) iteration.

First, guess a value for T_4. From the diagram, T_i, T_o and T_1 are computed from:

$$T_i = T_{amb} + (T_4 - T_{amb})\, e^{-\mu 2}$$

$$T_0 = T_i + \frac{{}_cA_c}{m_c c_c}\, I$$

$$T_1 = T_{amb} + (T_o - T_{amb}) e^{-\mu 1}$$

then, a new value for T_4 is computed from:

$$T'_4 = T_1 - (T_1 - T_s)\, \epsilon_1\, \frac{(mc)_{1min}}{m_c c_c}$$

If $T_4 = T'_4 \pm \epsilon$, where ϵ is the permissible error, then T_4 is the right temperature of the loop. If not, compute the gradient of:

$$Q = m_c c_c\, (T_1 - T_4)$$

with respect to T_4.

And a new guess for T_4 is then:

$$T_4 = T_4 - [\text{Grad } Q]^{-1}\, Q.$$

Reiterate until a satisfactory temperature is obtained. Having the right T_1 and T_4, we can compute the energy transferred to the storage.

$$q_f = m_c c_c\, (T_1 - T_4)$$

The energy balance for storage is then:

$$m_s c_s \frac{dT_s}{dt} = -q_\ell + q_f - q_{hotw}$$

Thus, T_s is determined.

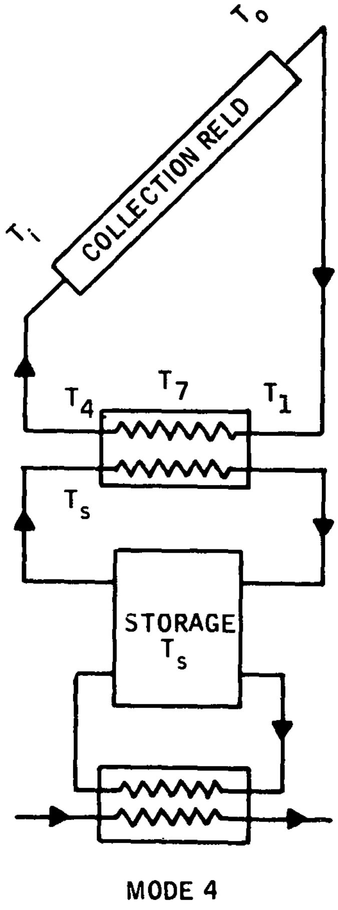


Figure E-10
Diagram for Mode 4.

Mode 5: Purging -- When $q_h = 0$ and the temperature of storage is at its boiling point, if there is insolation, the collected energy is discharged through a purge. From the diagram,

$$m_s c_s \frac{dT_s}{dt} = -q_\ell - q_{hotw}$$

T_s is then determined.

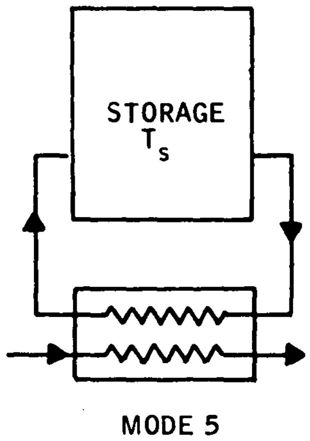


Figure E-11
Diagram for Mode 5.

Mode 6: Direct Cooling -- Mostly in summer, when the house needs cooling, and insolation is strong enough to run the Rankine cycle turbine, cool the house by the energy collected directly from the collectors.

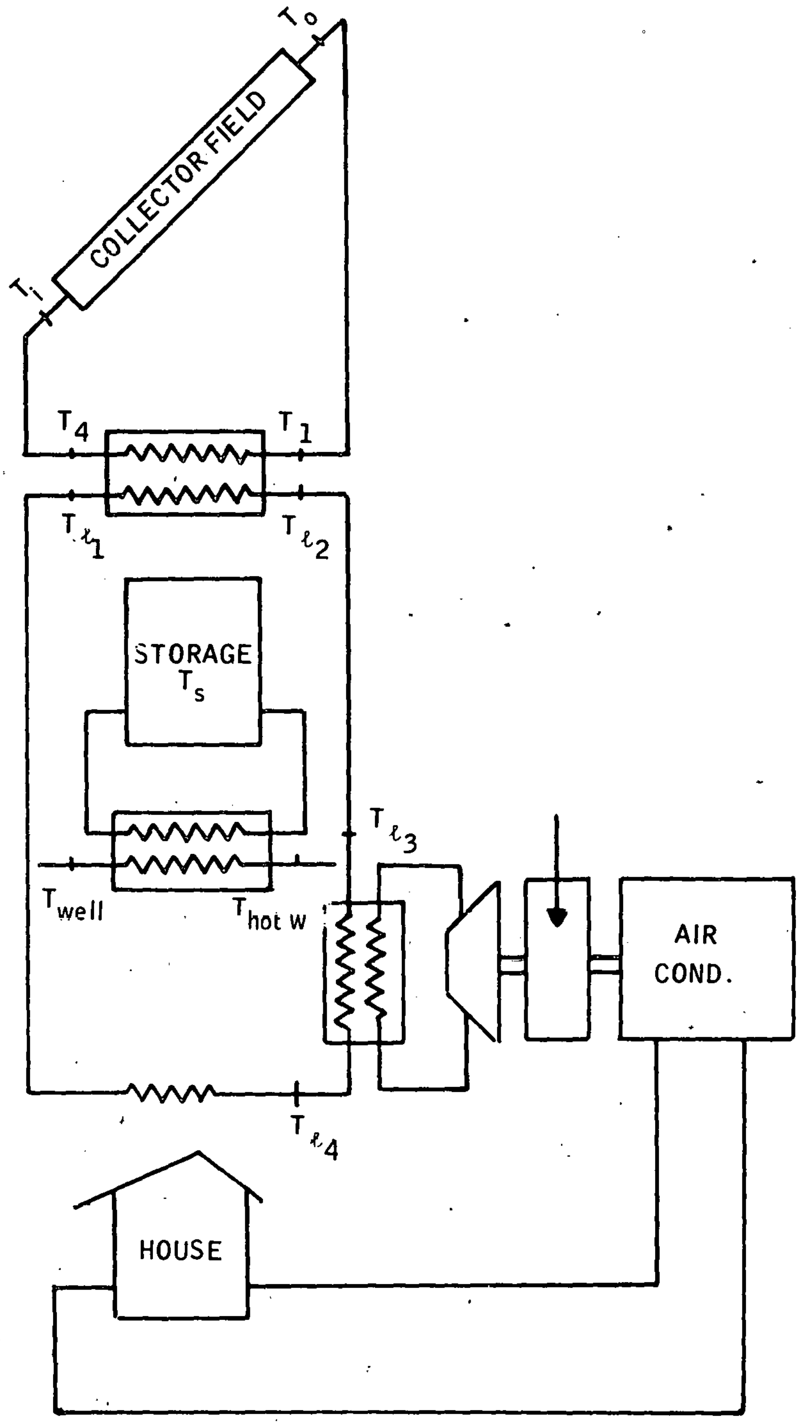


Figure E-12
Diagram for Mode 6.

The computational procedure is mostly the same as for Mode 2, the only difference is the transferred energy from the storage loop to the turbine. This energy is computed as follows:

For a temperature T_{ℓ_3}, η_t and q_t of the turbine is computed from (see Figure 5):

$$\eta_T = {}_T(T_{\ell_3})$$

$$q_t = q_t\,(T_{\ell_3})$$

The cooling capacity output from the air conditioning is:

capacity = q_t COP

In the variable speed air conditioner, the amount of auxiliary energy consumed is computed from the following equation:

$$q_h = \text{capacity} + q_{aux}$$

In the constant speed air conditioner, auxiliary energy is the amount of energy needed to bring the speed of the air conditioner up to it desired speed.

$$\text{capacity}/_{design} = \text{capacity} + q_{aux}$$

The solar energy supplied to the turbine is:

$$q_{solar} = \frac{q_t}{\eta_t}$$

Thus, the outlet turbine temperature is:

$$T_{\ell_4} = T_{\ell_3} - \frac{q_{solar}}{m_s c_s}$$

After the loop iterations, the right amount of cooling energy produced by the air conditioner is computed.

The storage energy balance is as follows:

$$m_s c_s \frac{dTs}{dt} = -q_\ell - q_{hotw}$$

T_s is determined from the above equation.

In this mode, the storage loop temperature may be higher than the design temperature for the Rankine turbine. In order to bring the loop temperature down to the design temperature, a purge is set up at the point T_{ℓ_2} to remove the excess energy. This excess energy is charged into storage for later use.

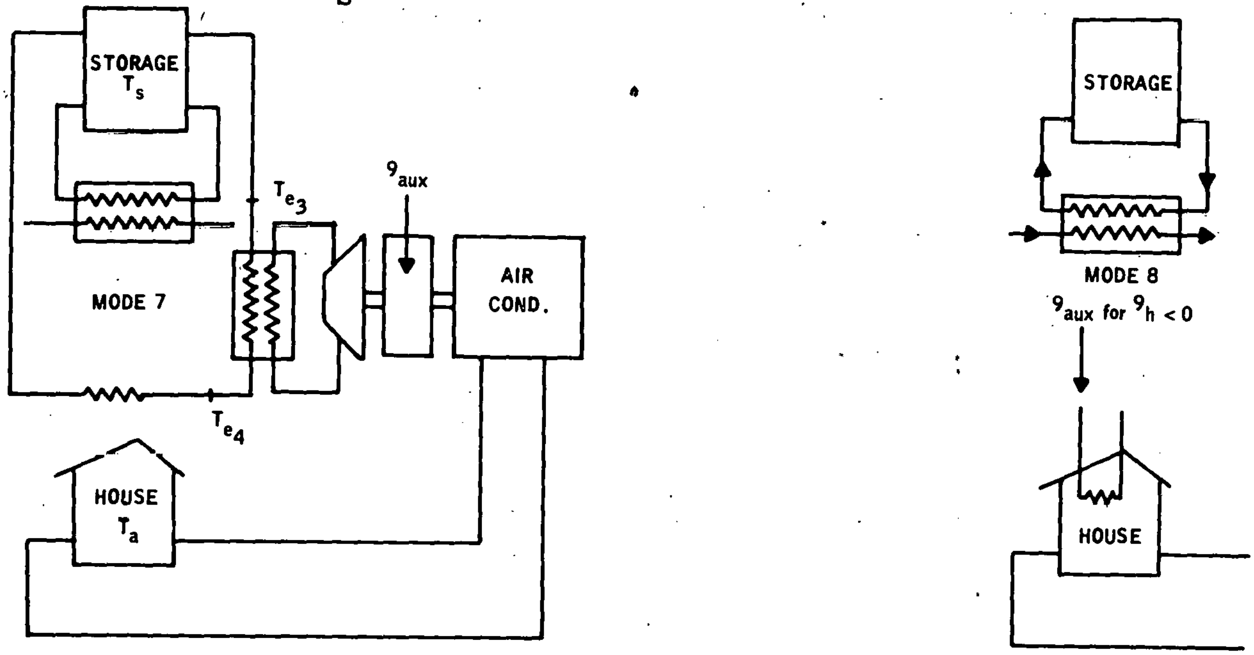
Mode 7: Cooling from Storage -- When there is a cooling load in the house, and insolation is not strong enough to supply power to the turbine, if the storage temperature is above some minimum temperature, cool the house with energy taken from storage.

The computations of air conditioner capacity, turbine power output and the amount of energy supplied to the turbine are similar to that in Mode 6.

Knowing the amount of energy furnished to the turbine, the energy balance for storage can be written as follows:

$$m_s c_s \frac{dTs}{dt} = -q_\ell - q'_{solar} - q_{hotw}$$

T_s can be computed from this equation.



Figures E-13 and E-14
Diagrams for Modes 7 and 8.

Mode 8: Sole Auxiliary Heating -- When the house needs heat, and there is not enough insolation, and the storage temperature is below some minimum, the auxiliary heat is turned on to supply the heating load.

The energy balance in the house is:

$$q_h + q_{aux} = 0$$

The energy balance for storage is:

$$m_s c_s \frac{dTs}{dt} = -q_\ell - q_{hotw}$$

T_s can computed from the previous equation

Mode 9: Sole Auxiliary Cooling -- When the house needs cooling and there is not enough heat to power the Rankine turbine either from the collector or from the storage, the auxiliary power line is turned on to run the air conditioner. The energy balance in the house is:

$$q_h + q_{aux} = 0$$

The energy balance for storage is:

$$m_s c_s \frac{dTs}{dt} = -q_\ell - q_{hotw}$$

T_s can be computed from the previous equation.

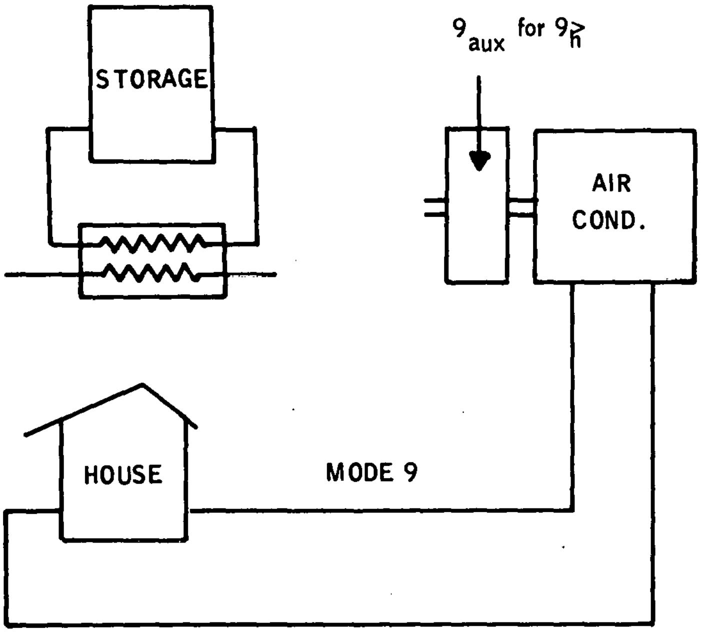


Figure E-15. Diagram for Mode 9

Mode Switching Logic and Time Fraction

The load of the house is the basic mechanism for mode switching. When the load is zero, normally the house stays in Mode 1, unless there is insolation and the storage needs to be charged up (Mode 4).

When there is a negative load (heating), it will check if the house can be heated from collector directly (Mode 2), or from the storage (Mode 3), or solely by auxiliary heater (Mode 8).

Assume that the system is in Mode 2. The collector will try to furnish the house load with all it can.

If the collected energy is more than the load of the house, q_h, the furnished energy, q_f, is:

$$q_f = q_h$$

The time fraction, f_t, it spends in this mode is:

$$f_t = \frac{q_f}{q_{coll}}$$

The rest of the time, $(1-f_t)$, is spent in charging storage (Mode 4) if the storage temperature is below the boiling point, or in purging if the storage temperature is at the boiling point (Mode 5).

If the collected energy is less than the load of the house, then the collected energy only furnishes part of the house load, and the time fraction spent in this mode is:

$$f_t = \frac{q_h}{q_t}$$

q_t is the possible heat transfer from storage for the whole integration time step. The system then returns back to Mode 1 the rest of the time.

If the storage temperature is lower than minimum, it will switch back to Mode 8 and heat the house using the auxiliary unit before returning to Mode 1. The time fraction spent in Mode 8 is:

$$f_t = \frac{q_h}{q_{auxD.}}$$ where $q_{anxD.}$ is the furnace capacity.

If there is no insolation, the system will start with Mode 3 and proceed as described above. When the house load is positive (cooling), the system will start with Mode 6 if there is enough insolation to power the Rankine turbine.

Depending on whether the air conditioner is constant speed or variable speed, the auxiliary power is added in now or later in Mode 9. The time fraction spent in this mode is:

$$f_t = \frac{q_h}{q_{cap}} \quad (q_{cap}\text{: capacity of air conditioner})$$

This expression is valid for both constant speed and variable speed air conditioners when the cooling capacity exceeds the house load.

For a variable speed air conditioner, $\left(q_{cap} < g_h\right)$*,

$$f_t = \frac{q_{cap}}{q_h}$$

The rest of the house load would be furnished by the auxiliary (Mode 9) or by storage (Mode 7).

For a constant speed air conditioner, the system will switch into Mode 4 to charge the storage if possible. For a variable speed air conditioner it will do so if there is more than enough insolation for the house load. If insolation is less than enough for the house load and the temperature of the storage is higher than some minimum, it will switch into Mode 7.

In Mode 7, the storage will supply energy to power the Rankine turbine. The air conditioner will supply the house with the load it requires. The time fraction spent in this mode is:

$$f_t = \frac{q_h}{q_{cap}}.$$

Then, it will switch back to Mode 1 whenever possible.

When the system is in Mode 8 or Mode 9, the auxiliary will be on until it furnishes the house load and then returns back to Mode 1. The flow chart for mode switching logics is presented on the next page.

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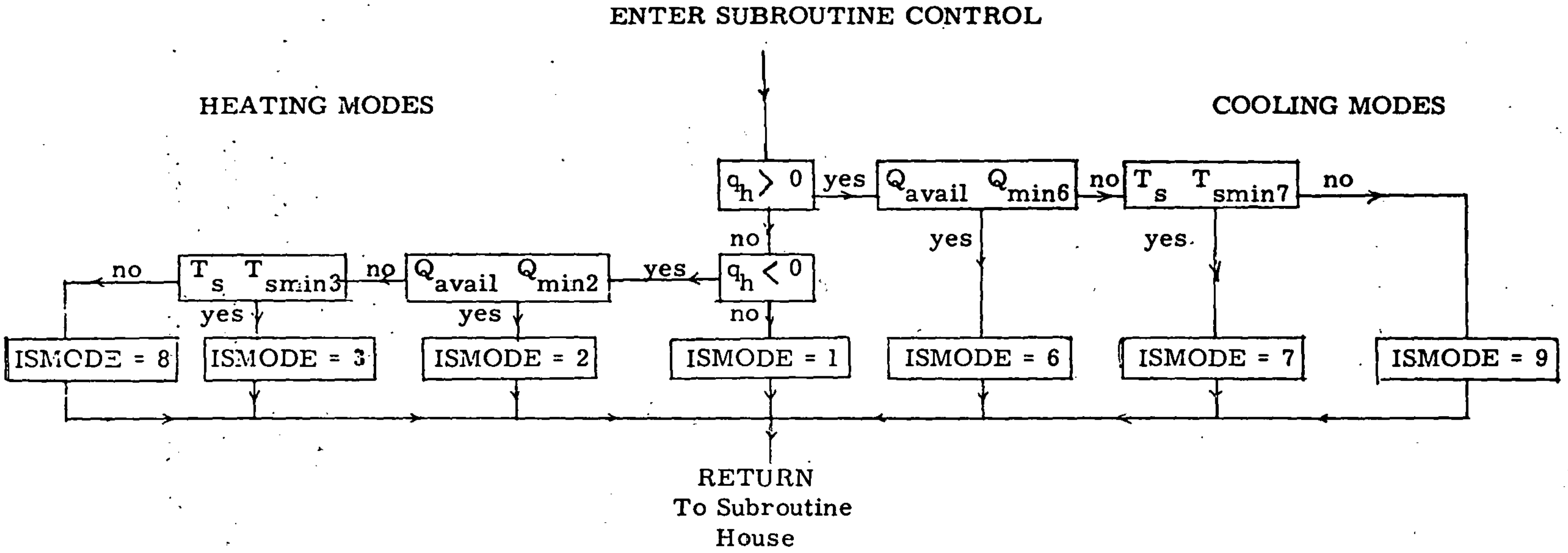
* The current simulation was revised so that the time fraction spent in this mode is one.



ISMODE = 1: Shut Down
2: Direct Solar Heating
3: Heating from Storage
4: Charge Storage
5: Purging
6: Direct Solar Cooling
7: Cooling from Storage
8: Sole Auxiliary Heating
9: Sole Auxiliary Cooling

Figure E-16

Flow Diagram for Mode Division in Subroutine CONTROL.

SUNSIM Program Glossary

X and XDOT Arrays

n	X (n) and/or XDOT (n)	Output Symbols
1	Direct normal radiation, cloud modified, Btu/ft^{2}hr	IDNC
2	Direct horizontal radiation, cloud modified, Btu/ft^2 hr	IDHC
3	Total horizontal radiation, cloud modified, Btu/ft^2 hr	ITHC
4	Direct radiation on the collector, Btu/ft^2 hr	QDIRCT
5	Diffuse radiation on the collector, Btu/ft^2 hr	QDIFUS
6	Total energy available after shading, Btu/ft^2 hr	QAVAIL
7	Total energy collected, Btu/hr	QCOLL
8	Heating load of the house, Btu/hr	QHOUSE
9	Energy demand for domestic hot water, Btu/hr	QHWTER
10	Auxiliary heating, Btu/hr	QAUX
11	Heat loss or gain from house to ambient, Btu/hr	QLOSHA
12	Solar energy furnished for domestic hot water, Btu/hr	QHWSOL
13	Heat loss from storage to house	QLOSSH
14	Storage temperature, °F	TSTOR
15	Time spent in shut-down mode, hr	MODE1
16	Time spent in direct solar heating mode, hr	MODE2
17	Time spent in heating from storage mode, hr	MODE3
18	Time spent in charging storage mode, hr	MODE4
19	Time spent in purging mode, hr	MODE5
20	Time spent in direct solar cooling mode, hr	MODE6
21	Time spent in cooling from storage mode, hr	MODE7
22	House load for cooling, Btu/hr	QHOUSS
23	Auxiliary cooling power, Btu/hr	WCAUX
24	Solar heat contribution for heating, Btu/hr	QSOL
25	Domestic hot water auxiliary, Btu/hr	QHWAUX
26	Air conditioner capacity, Btu/hr	QCSOL

SUNSIM Program Glossary (cont)

n	X (n) and/or XDOT (n)	Output Symbols
27	Time spent in sole auxiliary heating mode, hr	MODE8
28	Time spent in sole auxiliary cooling mode, hr	MODE9
29	Auxiliary power input, Kwh	PAUX
30	Output of excess power by Rankine turbine, Kwh	KWHO
31	Auxiliary electricity input, Kwh	KWHI
32	Excess energy due to high temperature in Mode 6, Btu/hr	QEXCES

DAY Array (Daily Sample Output)

	DAY Array	
1-7	See XDOT (1, 1) → XDOT (7, 1)	
8	Collector input temperature for Mode 2 or Mode 6	TCIN2
9	Ambient temperature	TAMB
10	Collector input temperature for Mode 4	TCIN4
11	Storage temperature, XDOT (14, 1)	TSTOR
12	See XDOT (12, 1)	QHWSOL
13	Cos θ, θ: angle of incidence	CTHETA
14	House load for winter	QHOUSE
15	See KDOT (11, 1)	QLOSHA
16-19	See XDOT (15, 1) → XDOT (18, 1)	
20	See XDOT (10, 1)	WAUX
21	Number of iteration steps in Mode 2 or Mode 6	MSTEP2
22	Number of iteration steps in Mode 4	MSTEP4
23	See XDOT (9, 1)	QHWTER
24-28	See XDOT (19, 1) → XDOT (23, 1)	
29	Collector output temperature in Mode 4	TCOUT4
30	Collector output temperature in Mode 2 and Mode 6	TCOUT2

DAY Array (cont)

31	Wet bulb temperature	TWET
32-41	See XDOT (24, 1) → XDOT (32, 1)	

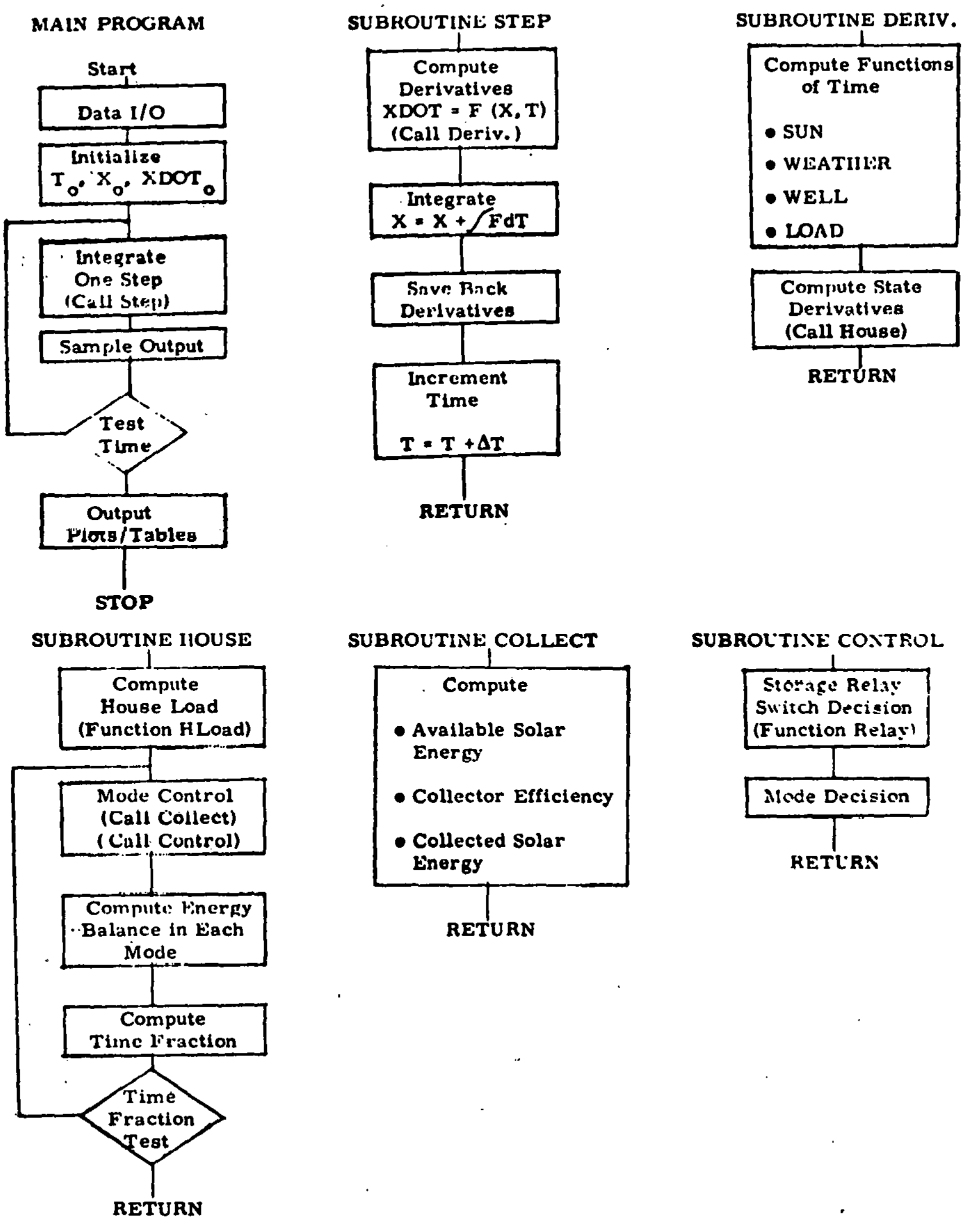


Figure E-17
Structure of SUNSIM Software

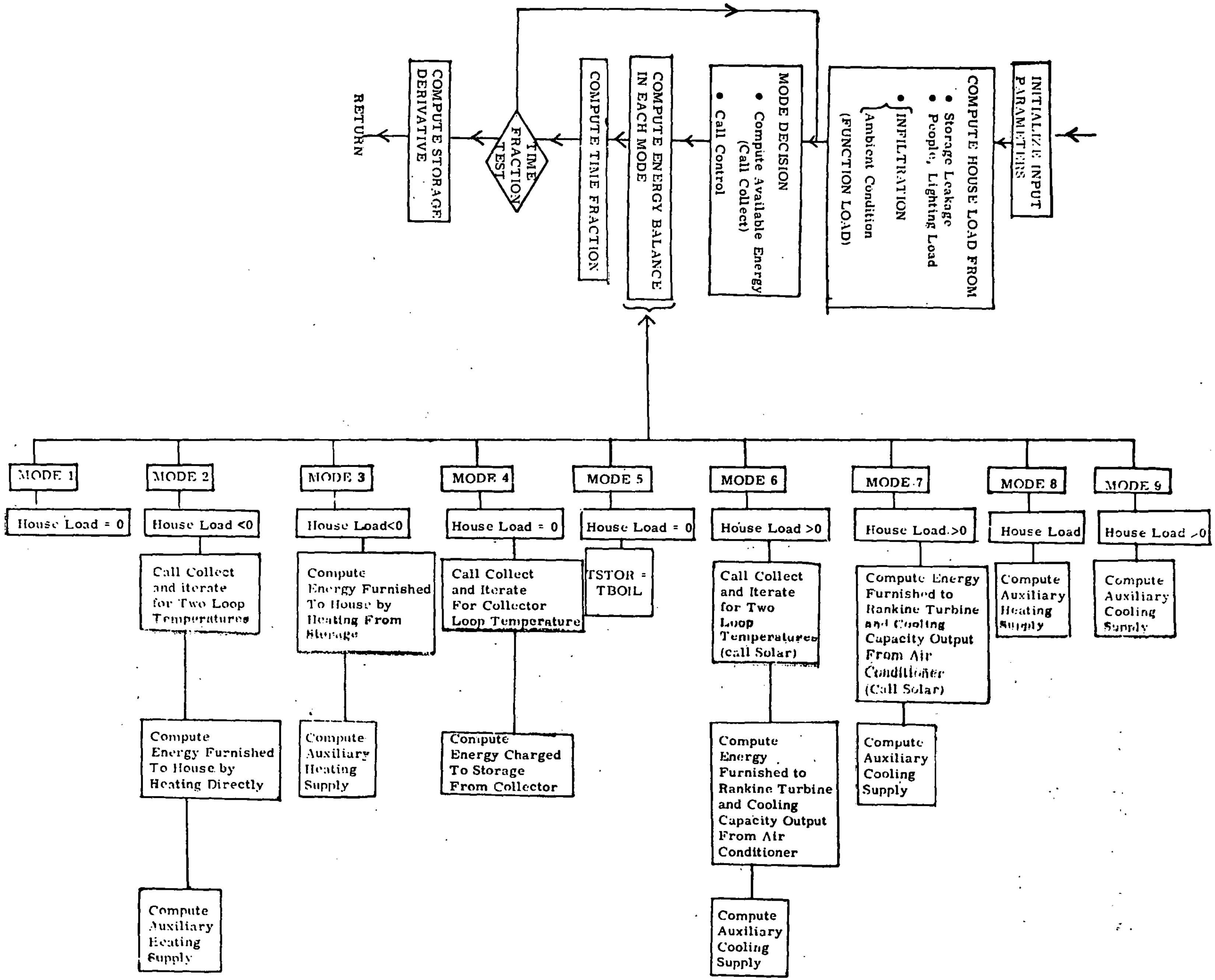
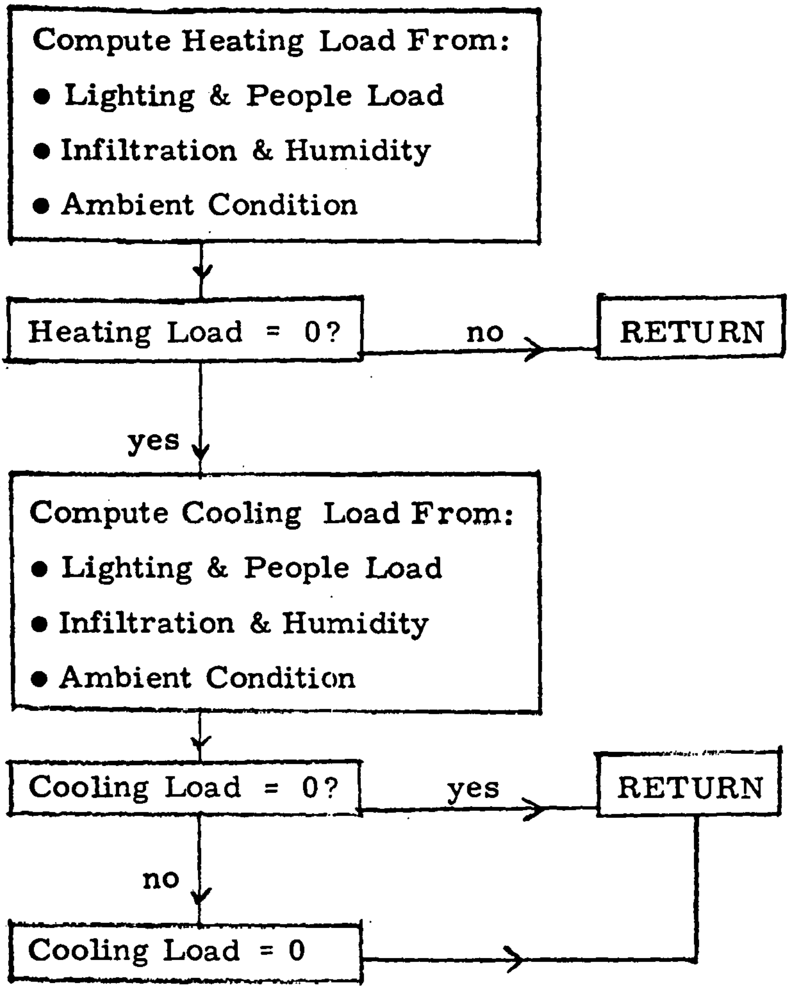


Figure E-18
Flow Diagram For Subroutine House

FUNCTION HLOAD



SUBROUTINE SOLAIR

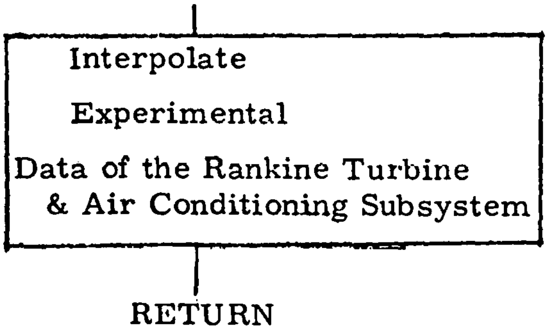


Figure E-18 (concluded)
Flow Diagram For Subroutine House

Computer Program

A general structure for the SUNSIM software is illustrated in Figure E-17. A detailed structure of the HOUSE routine is presented in Figure E-18.

A glossary of the terms in the HOUSE routine is documented with diagram illustrations at the end of this appendix.

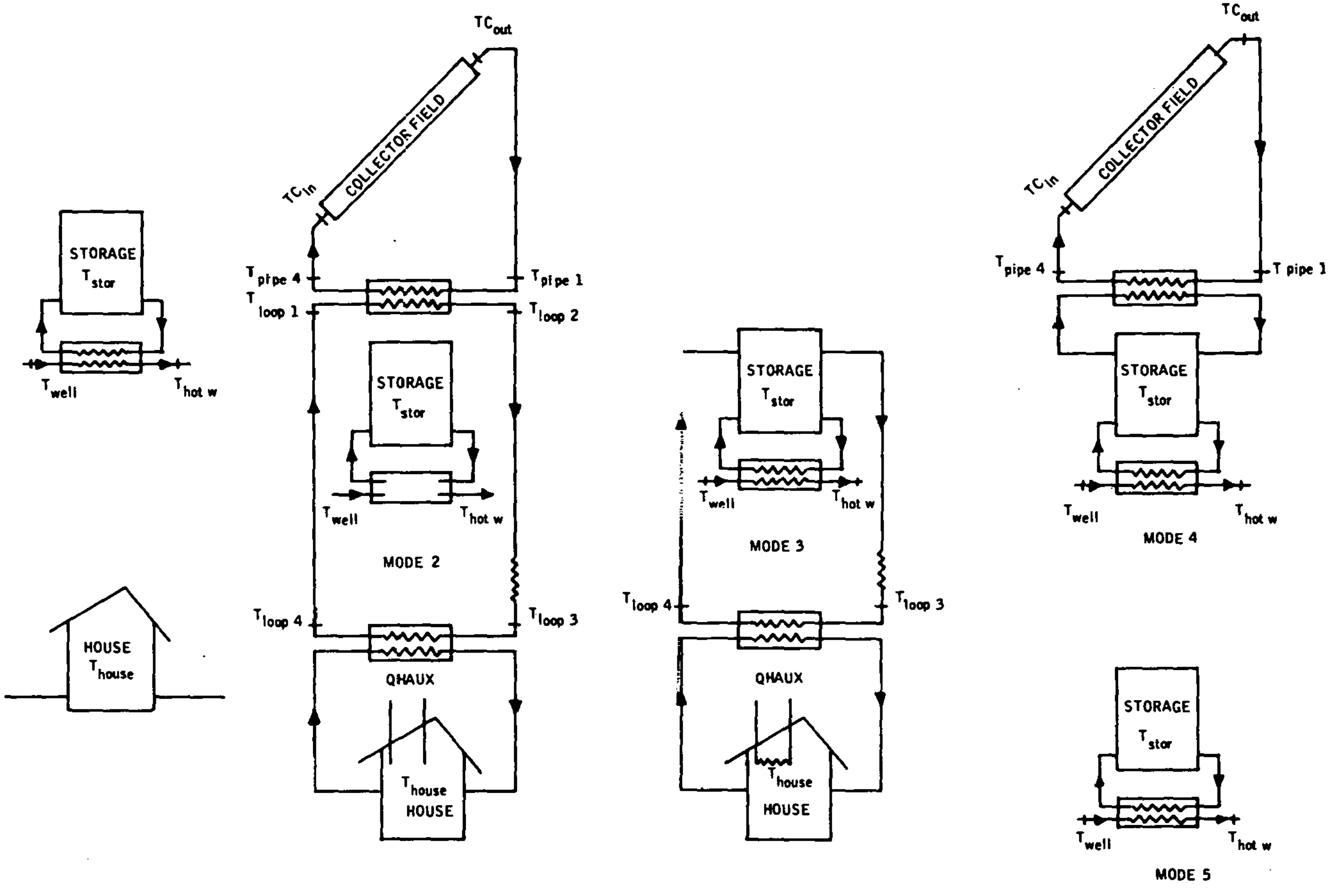


Figure E-19
Computer Program Nomenclature

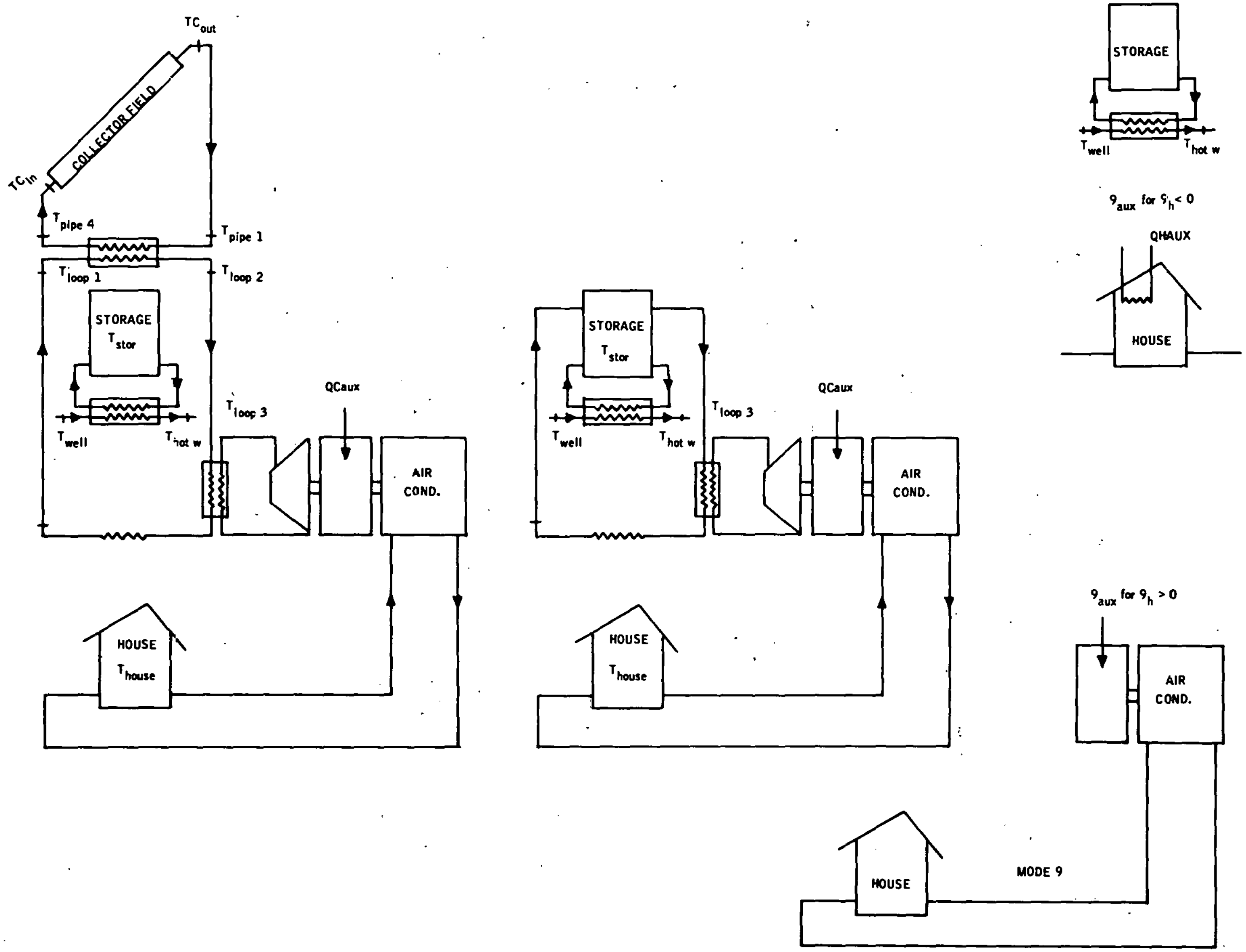


Figure E-19 (cont)
Computer Program Nomenclature

DYNSIM MODEL DESCRIPTION

The DYNSIM model is a dynamic simulation of a house equipped with a solar heating and hot water system. The schematic for this model is described in Figure E-20. It consists of a collector field, collector piping loop, a secondary piping loop connected to storage, a tertiary loop to extract heat from storage, and a storage tank.

The computational procedure for this model is based on the dynamic response of the systems. This more accurately describes the way the systems actually work because it takes into account the thermal capacitances of the materials composing the systems and their associated time constants. One disadvantage of this kind of procedure is that it demands a simulation step size smaller than the smallest time constant in order to avoid instabilities during computation. Obviously, the smaller the step the longer the run time needed to simulate a given time period.

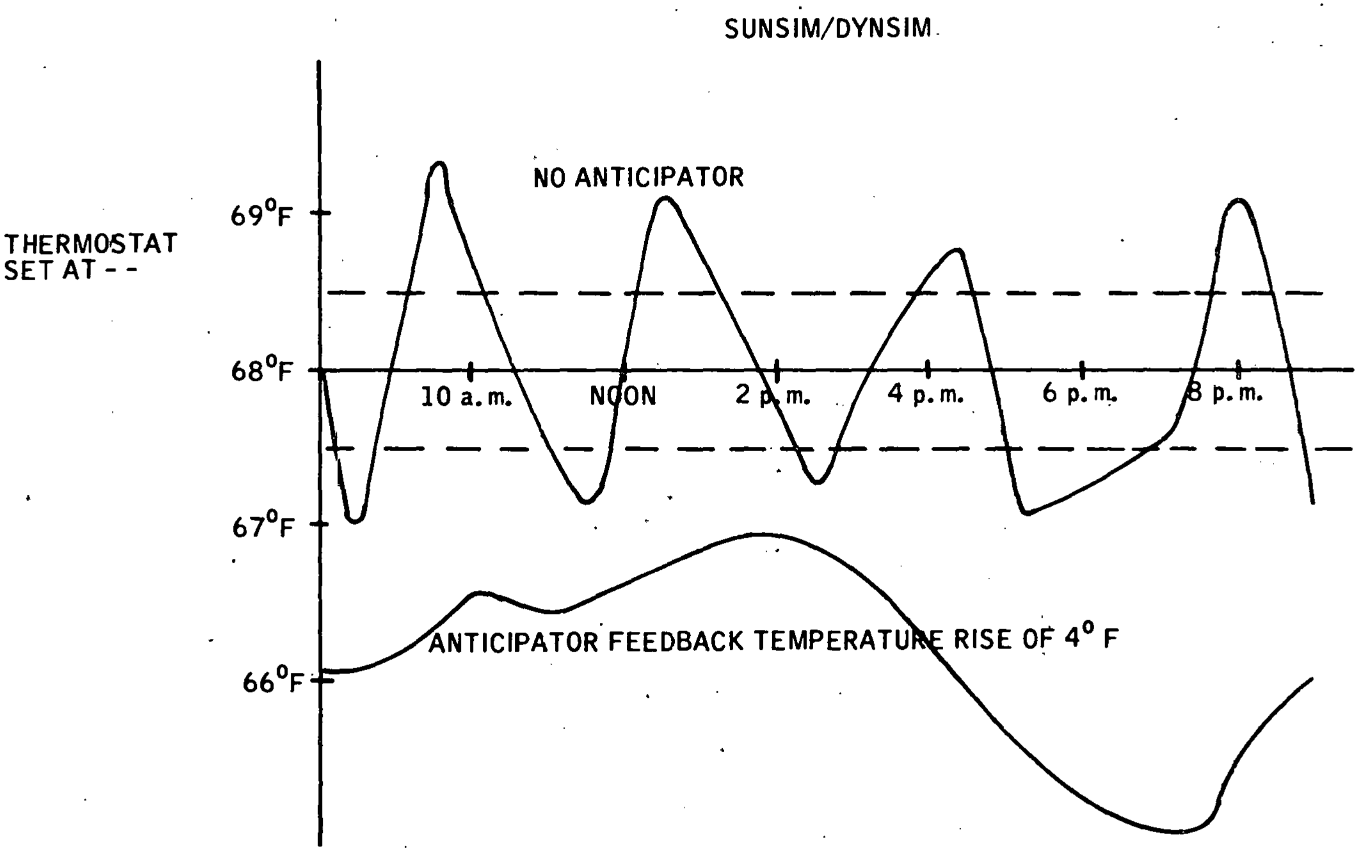
Basically, DYNSIM is a dynamic version of SUNSIM. The real differences between the two models lie in the way the temperatures in each component are calculated each time step, the manner in which the space conditioning needs are specified and met, and the fact that DYNSIM models thermal capacitances and time constants.

Collector Loop and Storage Loop

In DYNSIM the thermal capacitance of the entire collector loop is an input parameter (mc_pc) as is the thermal capacitance of the storage loop (mc_ps). The loop temperatures are calculated as follows for each time step.

Thermostat

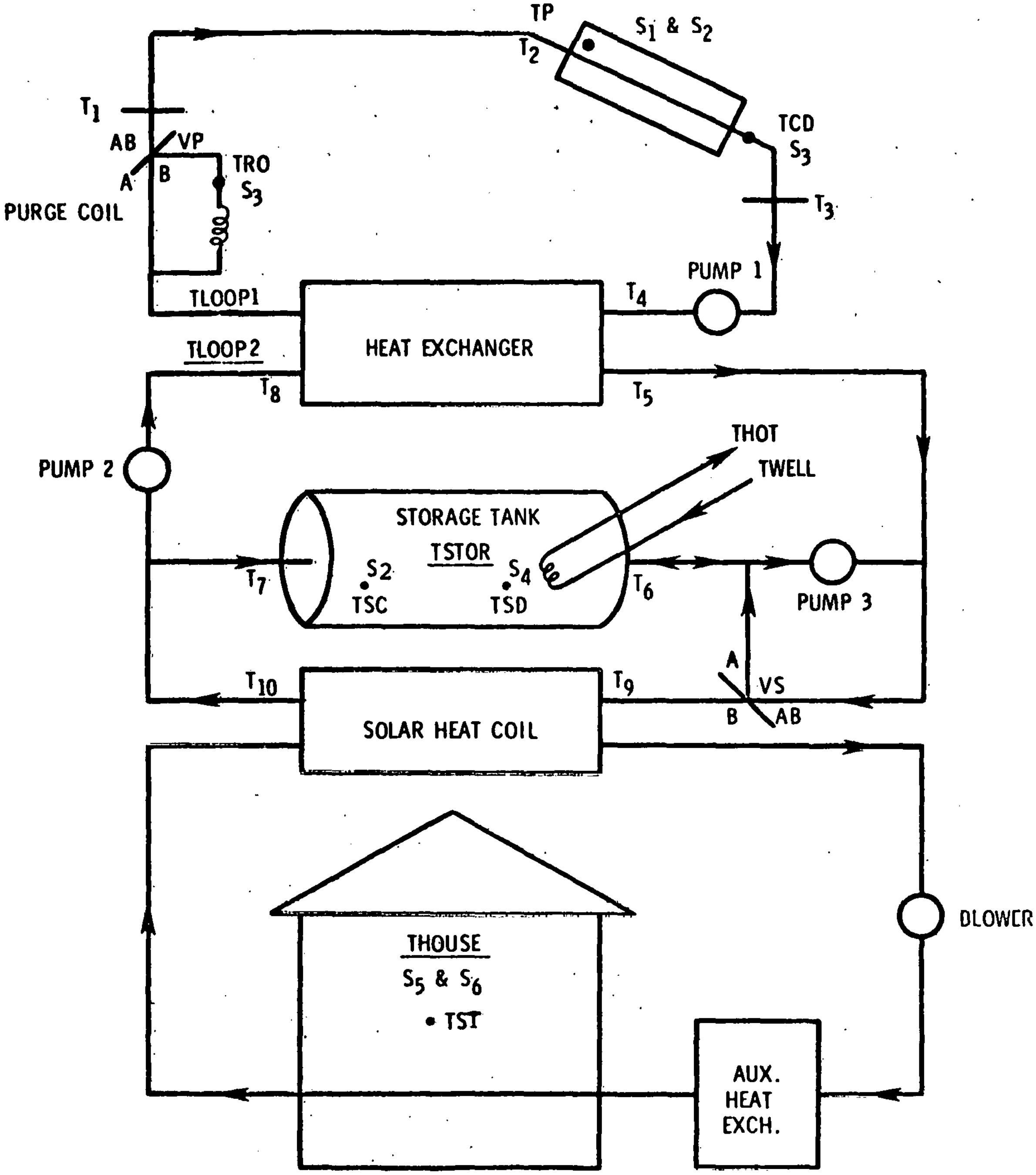
The thermostat is the sensor which determines when heating is required and when enough heat has been added. Since DYNSIM has time constants associated



Typical House Temperature Plot

Minneapolis, January 1, a clear day, with ambient temperatures from -5°F to +5°F

Figure E-20



MARV ANDERSON HOUSE

Figure E-21

with all masses, the air temperature and thermostat sensed temperature do not change at the same rate since the air and the thermostat have different time constants.

What this means is that the air temperature falls a couple of degrees below the thermostat setpoint before the thermostat sees a temperature which indicates that heating is called for. Once the heat is on, the air temperature normally rises faster than the thermostat sensor temperature causing the air temperature to be greater than the desired level. This means that more heat was added to the air than was desired and this wastes energy. Anticipators are added to the thermostat to handle this problem. Figure E-20 demonstrates their effect.

In this study, the house had a two stage thermostat (schematic in Figure E-22) which generally accompanies a solar heating system. Modeling of the thermostat requires three state variables -- the bimetal temperature and the anticipator for each stage.

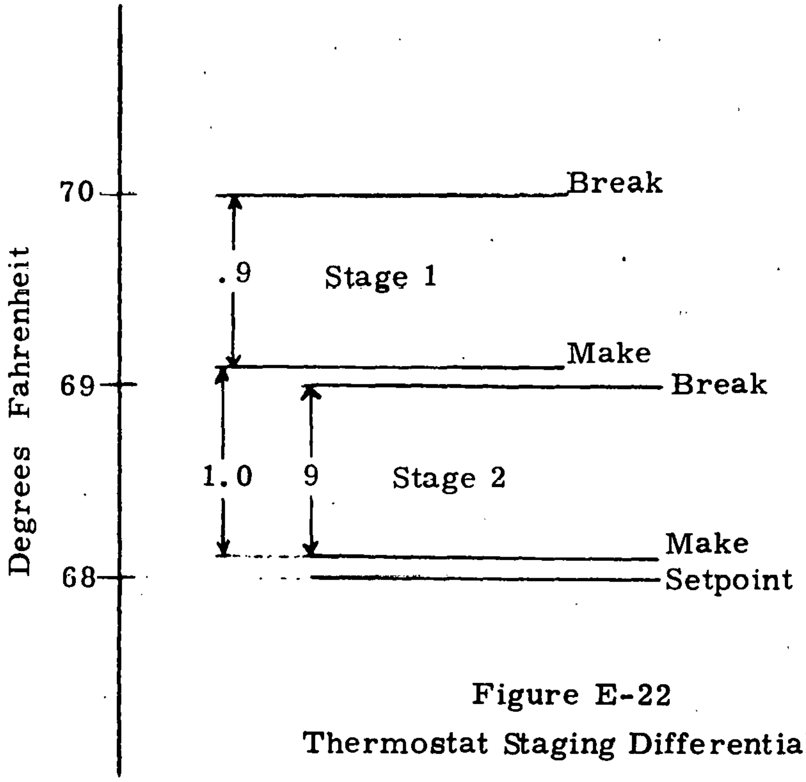


Figure E-22
Thermostat Staging Differentials

$$\dot{T}_c = [-U_1 (T_c - T_h) - U_2 (T_c - T_a) + Q_c - U_3 (T_c - T_a) - U_4 (T_c - T_h) - Q_{EX}] / \overline{mc_p c}$$

$$\dot{T}_s = [-U_5 (T_s - T_h) + Q_{EX} - Q_t - Q_s - U_6 (T_s - T_h)] / \overline{mc_p s}$$

T_a represents the ambient temperature and T_h the house temperature at an instant in time, t. The U's represent piping losses; Q_c solar energy collected (a function of collector loop temperature); Q_{EX} energy transferred through the heat exchanger (a function of the temperatures in the two loops); Q_t the energy added to or taken from the storage tank (a function of storage loop and storage tank temperatures); and Q_s the energy transferred to the building through the solar coil (a function of storage loop and building temperatures) during the time interval t to t +Δt. All the referenced temperatures are the current values at time t. This T_c represents the amount that the collector temperature changes during the interval t to t + Δt.

Storage Loop

The tank temperature dynamics are modeled as per the following equation:

$$\dot{T}_t = [Q_t - UA_t (T_t - T_h) - Q_{HW}] / \overline{mc_p t}$$

Q_t can be positive or negative depending on whether heat is being added or extracted from storage. UA_t is the thermal conductance of the storage tank surface and Q_{hw} is the energy withdrawn for domestic hot water needs (a function of tank temperature, well temperature and demand). $\overline{mc_p t}$ is the thermal capacitance of the tank, its contents and insulation.

Building

The objective of modeling any building and its internal loads is to determine an interior air temperature. It is this temperature, as seen by the appropriate sensor (i.e. the thermostat), which determines whether or not the space conditioning machinery needs to be used.

For this model, the house temperature (T_h) seen by the thermostat was modeled as:

$$T_h = (T_1 + T_2)/2$$

Where: T_2 = temperature of the surface of the wall which the thermostat is mounted on.

T_1 = temperature of the living room air as this is the room the thermostat is in.

The responses of these two temperatures to the stimuli of ambient temperature, solar flux through the windows, internal loads, basement temperature and heat addition from either the auxiliary furnace or the solar coil were modeled by a series of four transfer functions for each temperature. The transfer functions were developed from the Building Thermal Transfer Function (BTF) software package. This package was developed by Honeywell's Systems and Research Center for the digital computation of thermal transfer functions of buildings.

Table E-1 contains the eight transfer functions used to model the base house in Omaha. Q_{sol} is the amount of solar energy transmitted through the living room windows and Q_h is the heat added to the house by the heating system and internal loads.

$$\frac{T1}{T0} = \frac{.56543(84.60s + 1)(3.94s + 1)}{(825.01s + 1)(36.17s + 1)(.634s + 1)}$$

$$\frac{T1}{T3} = \frac{.434565}{(830.37s + 1)(23.87s + 1)(.596s + 1)}$$

$$\frac{T1}{Q_{sol}} = \frac{.00462(124.46s + 1)(3.54s + 1)}{(636.68s + 1)(64.28s + 1)(1.09s + 1)}$$

$$\frac{T1}{Q_h} = \frac{.00284(247.85s + 1)(5.05 + 1)}{(796.23s + 1)(36.38s + 1)(.706s + 1)}$$

$$\frac{T2}{T0} = \frac{.53444}{(1164s + 1)(9.55s + 1)}$$

$$\frac{T2}{T3} = \frac{.46556(520.70s + 1)(7.86s + 1)}{(1260.98s + 1)(448.33s + 1)(55.17s + 1)(5.52s + 1)}$$

$$\frac{T2}{Q_{sol}} = \frac{.004336(95.18s + 1)}{(752.34s + 1)(70.62s + 1)}$$

$$\frac{T2}{Q_h} = \frac{.0021143(11.79s^2 + 2.95s + 1)}{(923.88s + 1)(5.42s + 1)(1.48s + 1)}$$

Table E-1

Transfer Functions for Base House

The first stage of the thermostat controls the solar heating system which is activated whenever the house temperature drops below 69°F. The associated anticipator (A), is set to a non-zero θ_1. The second stage controls the auxiliary furnace and is activated when the house temperature falls below 68°F and the anticipator (A_2) is set equal to a non-zero θ_2.

$$\dot{T}_{A1} = \frac{1}{r} [\theta_1 - T_{A1}]$$
$$\dot{T}_{A2} = \frac{1}{r} [\theta_2 - T_{A2}]$$

The effect of the anticipators is to decrease the amount by which the air temperature overshoots the breakpoint when heat is being added. The thermostat temperature that becomes the driver in the control system is then:

$$T_{ST} = T_B + T_{A1} + T_{A2}.$$

In the study house thermostat model, the anticipators are set at 1.95°F and have time constants of $\tau_1 = \tau_2 = 8$ minutes.

Figure E-23 contains a dictionary of the X array and Figures E-24 through E-28 contain a listing of the algorithms used to model the building dynamics and the heating system.

Control System

Another feature of DYNSIM is the totally isolated control software package. Included are the various switches which, as functions of the sensors, set the blowers, pumps and valves according to the ladder diagram in Figure E-27.

With the control software as written, various control strategies can be simulated without disturbing the other system models. The control system is sketched out in Figure E-29.

X ARRAY DICTIONARY

State Variables (Degrees Fahrenheit)

X_{41}	TLOOP1	Temperature in collector loop
X_{42}	TLOOP2	Temperature in storage loop
X_{43}	TSTOR	Temperature in storage tank
X_{44}	STSC	Sensor Temperature at TSC
X_{45}	STSD	Sensor Temperature at TSD
X_{46}	THOUSE	Temperature in house
X_{47}	STST	Bimetal Temperature
X_{39} & X_{40}		Anticipators, first and second stage (DANT)

Cumulative Values of Energy Variables (BTUs)

X_1	IDNC	Direct normal solar radiation
X_2	IDHC	Direct horizontal solar radiation
X_3	ITHC	Total horizontal solar radiation
X_4	QDIRCT	Direct radiation on the collector
X_5	QDIFUS	Diffuse radiation on the collector
X_6	QAVAIL	Total radiation on the collector
X_7	QPLATE	Energy absorbed by collector plate
X_8	QLPIP1	Energy lost in line to collectors
X_9	QLPIP2	Energy lost in line back to heat exchanger
X_{10}	QCLOSS	Energy lost from collectors (Pump off)
X_{11}	QPURGE	Energy lost when purge fan is on
X_{12}	QCOLL	Energy collected
X_{13}	QWINDO	Energy transmitted through windows (south)
X_{14}	QHWDEM	Hot Water energy required
X_{15}	QHWSOL	Hot Water energy furnished by storage tank
X_{16}	QLTANK	Energy loss from storage tank
X_{17}	QLHOUSE	Energy loss from house

Figure E-23
X Array Dictionary

Cumulative Values of Energy Variables (BTUs) - continued

X_{18}	QAUX	Energy furnished by auxiliary furnace
X_{19}	QEXCH	Energy transmitted through heat exchanger
X_{20}	QCOIL	Energy transmitted through solar coil
X_{21}	QLPIP3	Energy loss in storage loop line
X_{22}	QSTOR	Energy stored in tank
X_{23}	QSOLAR	Energy furnished by collectors to house

Cumulative Record of Nominal Operating Modes (Hours)

X_{25}	MODE 1	Heat house from sun
X_{26}	MODE 2	Charge storage tank
X_{27}	MODE 3	Heat house from storage tank
X_{28}	MODE 4	Turn off storage loop
X_{29}	MODE 5	Error-Recheck ladder diagram

Cumulative Record of Hardware Settings (Hours)

X_{31}	PGFAN	Purge fan/coil On
X_{32}	PUMP1	Pump 1 On
X_{33}	PUMP2	Pump 2 On
X_{34}	PUMP3	Pump 3 On
X_{35}	BLOWER	Furnace blower On
X_{36}	GAS	Gas valve On
X_{37}	VS	Direct valve at AB/B
X_{38}	VP	Purge valve at B/AB

Figure E-23

X Array Dictionary (concluded)

```
SUBROUTINE HOUSE

CALL CONTROL

Initialize Temperatures,
$TRO = T_1 = T_2 = TP = TCD = T_3 = T_4 = X_{41}$                                      TLOOP1
$T_5 = T_6 = T_7 = T_8 = T_9 = T_{10} = X_{43}$                                        TLOOP2
$TSC = TSD = X_{43}$                                                                   TSTOR
If ($\dot{X}_{32} = 1$) GO TO 20

Pump 2 is off
CALL COLLECT ($T_2$, QC)

$\dot{X}_7 = QC \cdot A_{coll} \cdot N_{parl} \cdot N_{series}$                         QPLATE
$\dot{X}_8 = UL_1 (X_{41} - X_{46}) + UL_2 (X_{41} - T_a)$                             QLPIP1
$\dot{X}_9 = UL_3 (X_{41} - T_a) + UL_4 (X_{41} - X_{46})$                             QLPIP2
If ($\dot{X}_7 = 0$) $X_{10} = UL_c (X_{41} - T_a) A_{coll} \cdot N_{parl} \cdot N_{series}$     QCLOSS
GO TO 60

Pump 1 is on
20 If ($\dot{X}_{31} = 1$) $\dot{X}_{11} = (X_{41} - T_a)e^{-UA_{coil}/\dot{m}cs}$       $X_{46}$ is THOUSE
   $T_1 = X_{46} + (TRO - X_{46})e^{-UA_1/\dot{m}cc}$
   $T_2 = T_a + (T_1 - T_a)\, e^{-UL_2/\dot{m}cc}$
   $\dot{X}_8 = (TRO - T_2)\, mcc$                                                     QLPIP1
   $T_{inter} = T_2$
   Do 30 n = 1, $N_{series}$
   CALL COLLECT ($T_{inter} + \Delta T/2$, QC)
   $\Delta T = QC \cdot A_{coll} \cdot N_{parl}/\dot{m}cc$
```

Figure E-24
Subroutine House

```
   $T_{inter} = T_{inter} + \Delta T$
30 $\dot{X}_{12} = \dot{X}_{12} + QC \cdot A_{coll} \cdot N_{parl}$                    QCOLL
   $TCD = T_{inter}$
   $T_3 = T_a + (TCD - T_a)\, e^{-UL_3/\dot{m}cc}$
   $T_4 = X_{46} + (T_3 - X_{46})\, e^{-UL_4/\dot{m}cc}$
   $\dot{X}_9 = (TDC - T_4)\, \dot{m}cc$                                       QLPIP2

   Compute Solar Radiation on South Windows
60 $\cos\theta = \sin(azim)\, Y_{SLV} - \cos(azim)\, Z_{SLV}$
   $Q_{DIF} = (\dot{X}_3 - \dot{X}_2 + \rho \cdot \dot{X}_3)(.315 \cos\theta^2 + .424 \cos\theta + .549)$
   If $(\cos\theta < 0)$ $\cos\theta = 0$
   $Q_{DIR} = \cos\theta \cdot \dot{X}_1$
   $\dot{X}_{13} = (Q_{DIF} + Q_{DIR})\, A_{WINDO} \cdot \eta$                    QWINDO

   Compute House Loads
   CALL HLOAD
```

Figure E-24

Subroutine House (concluded)

SUBROUTINE HLOAD

Compute Domestic Hot Water Requirements

$\dot{X}_{14} = \dot{m}c_{HW} (T_{HW} - T_{WELL})$ QHWDEM

$T_{OUT} = TSD + (T_{WELL} - TSD)e^{-UA/mc_{HW}}$

If $(T_{OUT} > T_{HW})$ $T_{OUT} = T_{HW}$

$\dot{X}_{15} = \dot{m}c_{HW} (T_{OUT} - T_{WELL})$ QHWSOL

Compute People, Lighting and Appliance Loads for the Hour

$\dot{X}_{30}$ = PEOPLE(HOUR) + LIGHTS (HOUR) + APPLIANCE (HOUR) QINT

Compute Storage Tank Loss to House

$\dot{X}_{16} = (X_{43} - X_{46}) * \text{UATANK}$ QLTANK

Compute Auxiliary Furnace Contributions

DTM = DT * 60/4

$\dot{X}_{18} = \dot{X}_{36} * \text{QFURN} * \text{DTM} + \dot{X}\text{OLD} * (1\text{-DTM})$

$\dot{X}\text{OLD} = \dot{X}_{18}$

RETURN
END

Figure E-25
Subroutine HLoad

PROCEED ACCORDING TO SETTINGS OF VALVES AND PUMPS

Pump 2 on, Pump 3 off, and VS (AB, B)

I ($\dot{X}_{33} = 1$ and $\dot{X}_{34} = 0$ and $\dot{X}_{37} = 1$) TO TO 100

Pump 2 on, Pump 3 off, and VS (AB, A)

If ($\dot{X}_{33} = 1$ and $\dot{X}_{34} = 0$ and $\dot{X}_{37} = 0$) GO TO 200

Pump 2 off, Pump 3 on, and VS (AB, B)

If ($\dot{X}_{33} = 1$ and $\dot{X}_{34} = 1$ and $\dot{X}_{37} = 1$) GO TO 300

Pump 2 off, Pump 3 off, and VS (AB, A)

If ($\dot{X}_{33} = 0$ and $\dot{X}_{34} = 0$ and $\dot{X}_{37} = 0$) GO TO 400

ERROR MODE

$\dot{X}_{29} = 1$

GO TO 500

Heat House Directly from Sun

100 $\dot{X}_{25} = 1$ MODE 1

$\dot{X}_{19} = \epsilon_x(T_4 - X_{42})\dot{m}cc$ $\dot{m}cc \leq \dot{m}cs$ QEXCH

$T_5 = X_{42} + \dot{X}_{19}/\dot{m}cs$

$T_9 = X_{46} + (T_5 - X_{46})\, e^{-UL_5/\dot{m}cs}$

FIGURE E-26

PROCEED ACCORDING TO SETTINGS OF VALVES AND PUMPS

$\dot{X}_{20} = \epsilon_c (T_9 - X_{46}) \dot{m}cs$ $\dot{m}cs \le \dot{m}ch$ QCOIL

$T_{10} = T_9 - \dot{X}_{20}/\dot{m}cs$

$T_8 = X_{46} + (T_{10} - X_{46}) c^{-UL_6/\dot{m}cs}$

$\dot{X}_{21} = (T_5 - T_9 + T_{10} - T_8) \dot{m}cs$ QLPIP3

GO TO 500

Charge Storage Tank

200 $\dot{X}_{26} = 1$ MODE 2

$T_7 = TSC$

$T_8 = X_{46} + (T_7 - X_{46}) e^{-UL_8/\dot{m}cs}$

$X_{19} = \epsilon_x (T_4 - T_8) \dot{m}cc$ $\dot{m}cc \le \dot{m}cs$ QEXCH

$T_5 = X_{42} + X_{19}/\dot{m}cs$

$T_6 = X_{46} + (T_5 - X_{46}) e^{-UL_5/\dot{m}cs}$

$\dot{X}_{22} = (T_6 - X_{43}) \dot{m}cs$ $\dot{X}_{24} > 0$ QSTOR

$\dot{X}_{21} = (T_5 - T_6 + T_7 - T_8) \dot{m}cs$ QLPIP3

GO TO 500

Heat from Storage Tank

300 $\dot{X}_{27} = 1$ MODE 3

$T_6 = TSD$

FIGURE E-26 (continued)
Proceed According to Settings of Valves and Pumps

$T_9 = X_{46} + (T_6 - X_{46})\, e^{-UL_7/\dot{m}cs}$

$\dot{X}_{20} = \epsilon_c\, (T_9 - X_{46})\, \dot{m}cs$ $\dot{m}cs \le \dot{m}ch$ QCOIL

$T_{10} = T_9 - \dot{X}_{20}/\dot{m}cs$

$T_7 = X_{46} + (T_{10} - X_{46})\, e^{-UL_8/\dot{m}cs}$

$\dot{X}_{21} = (T_6 - T_9 + T_{10} - T_7)\, \dot{m}cs$ QLPIP3

$\dot{X}_{22} = (T_7 - X_{43})\, \dot{m}cs$ QSTOR

GO TO 500

Turn off Storage Loop

400 $\dot{X}_{28} = 1$ MODE 4

$X_{21} = (UL_5 + UL_6 + UL_7 + UL_8 + UL_9)\, (X_{42} - X_{46})$ QLPIP3

Compute State Derivatives

Temperature in the Collector Loop --

500 $\frac{d\,(T\ LOOP1)}{dt}$ = (QCOLL + QPLATE - QPURGE - QLPUP1 - QCLOSS - QLPIP2 - QEXCH) /mcc

$\dot{X}_{41} = (\dot{X}_{12} + \dot{X}_7 - \dot{X}_{11} - \dot{X}_8 - \dot{X}_{10} - \dot{X}_9 - \dot{X}_{19}) \,/mcc$

Temperature in the Storage Loop --

$\frac{d(T\ LOOP2)}{dt}$ = (QEXCH - QCOIL - QLPIP3 - QSTOR) /mcs

$\dot{X}_{42} = (\dot{X}_{19} - \dot{X}_{20} - \dot{X}_{21} + \dot{X}_{22}) \,/mcs$

FIGURE E-26 (continued)

Proceed According to Settings of Valves and Pumps

LADDER DIAGRAM

Set Purge Coil (R_1)

If (S_3 = 1) $\dot{X}_{31}$ = 1

Set Pump 1 (R_2)

If (S_1 = 1) $\dot{X}_{32}$ = 1

Set Pump 2 (R_3)

If (S_1 = 1 and S_3 = 0 and S_5 = 0) $\dot{X}_{33}$ = 1

If (S_1 = 1 and S_2 = 1 and S_3 = 0 and S_5 = 1) $\dot{X}_{33}$ = 1

Set Pump 3 (R_4)

If (S_1 = 0 and S_4 = 1 and S_5 = 0) $\dot{X}_{34}$ = 1

If (S_3 = 1 and S_4 = 1 and S_5 = 0) $\dot{X}_{34}$ = 1

Set Furnace Blower (R_5)

If (S_5 = 0) $\dot{X}_{35}$ = 1

Set Gas Valve (R_6)

If (S_6 = 0) $\dot{X}_{36}$ = 1

Set divert Valve VS (R_7)

If (S_1 = 1 and S_3 = 0 and S_5 = 0) $\dot{X}_{37}$ = 1

FIGURE E-26
Ladder Diagram

```
If ($S_1 = 0$ and $S_4 = 1$ and $S_5 = 0$) $\dot{X}_{37} = 1$
IF ($S_3 = 1$ and $S_4 = 1$ and $S_5 = 0$) $\dot{X}_{37} = 1$

Set Purge Valve VP ($R_8$)

If ($S_8 = 1$) $\dot{X}_{38} = 1$

RETURN

END
```

FIGURE E-27 (concluded)
Ladder Diagram

```
FUNCTION SWITCH ($T_1$, $T_2$, S, $T_{in}$)

SWITCH = S

If (SWITCH = 0 and $T_{in} \geq T_2$) SWITCH = 1

If (SWITCH = 1 and $T_{in} \leq T_1$) SWITCH = 0

RETURN

END
```

FIGURE E-28
Function Switch (T_1, T_2, S, T_{in})

SUBROUTINE CONTROL

Software Coding for Sensor Switches ($S = 0, 1$)

Switch at TP

$S_1 = \text{SWITCH}(100, 100, S_1, X_{41})$

Switch at TP/TSC

$S_2 = \text{SWITCH}(X_{44}, X_{44}, S_2, X_{41})$

Switch at TRO/TCD

$S_3 = \text{SWITCH}(220, 205, S_3, X_{41})$

Switch at TSD

$S_4 = \text{SWITCH}(100, 100, S_4, X_{45})$

First Stage Thermostat Switch at TST

$S_5 = \text{SWITCH}(69.0, 69.9, S_5, X_{47} + X_{39} + X_{40})$

Second Stage Thermostat Switch at TST

$S_6 = \text{SWITCH}(68, 68.9, S_6, X_{47} + X_{39} + X_{40})$

FIGURE E-29

Subroutine Control

Builder/Developer	Marvin H. Anderson Construction Company Minneapolis, Minnesota	
Solar Hardware Developer	Honeywell, Inc. 2600 Ridgway Parkway Minneapolis, Minnesota	
Solar Hardware Manufacturer	Lennox Industries, Inc. Marshalltown, Iowa	
Solar Hardware Installer	George Sedgwick Heating Company Minneapolis, Minnesota	
House Spec.	Standard residential architecture 1300 ft^2 living area on main floor, total 1780 ft^2 finished space, 2530 ft^2 heated Split entry 9948 Nesbitt Circle Bloomington, MN (Hyland Hills)	
	Energy Conserving Features: ● Triple glaze windows ● 10 inch cellulose attic insulation (R36) ● Thermostat controlled attic fan ● 2 inch Dow Corning styrofoam sheating on with 3-1/2 inch Fiberglas batting (R25)	
	Sale price -- \$89,500	
Solar Spec.	378 ft^2 collectors (21 - 6 ft x 3 ft panels) Provides 55 percent of space heat, 68 percent of domestic hot water Storage tank: 1000 gallons	
HUD Grant	Total Amount - \$16,250	
	Total Estimated Cost of Solar System -	\$18,000
	Total to Honeywell for Engineering and Collectors --	\$10,900
	Total to Sedgwick for Installation Labor and Material --	\$ 4,851
Operating Cost	Projected fuel bill (gas) --	\$ 300/yr.
Solar Contribution	Heating and Hot Water (58 percent)	\$ 174/yr

FIGURE E-30
Project Summary for Equinox Solar Home

Simulation Results

A 24-hour simulation of the Marv Anderson house solar heating system has been completed. The selected day for the simulation was November 19, 1976. (See Table E-2).

Figure E-29 is a graph of the simulation study results and Figure E-30 is a graph of the actual results observed during operation of the Marv Anderson house. As can be seen, the simulation results correlate well with the actual observed trends. An important result to notice is that the actual observed collector efficiency (49 percent for the study day was higher than the collector efficiency predicted by DYNSIM (44 percent). This is significant in that it indicates that using DYNSIM to predict how the solar system will work under a given set of conditions does not produce an artifically optimistic assessment.

EQUINOX SOLAR HEATING SYSTEM - 24 HOUR SIMULATION

NOVEMBER 16-17, 1976

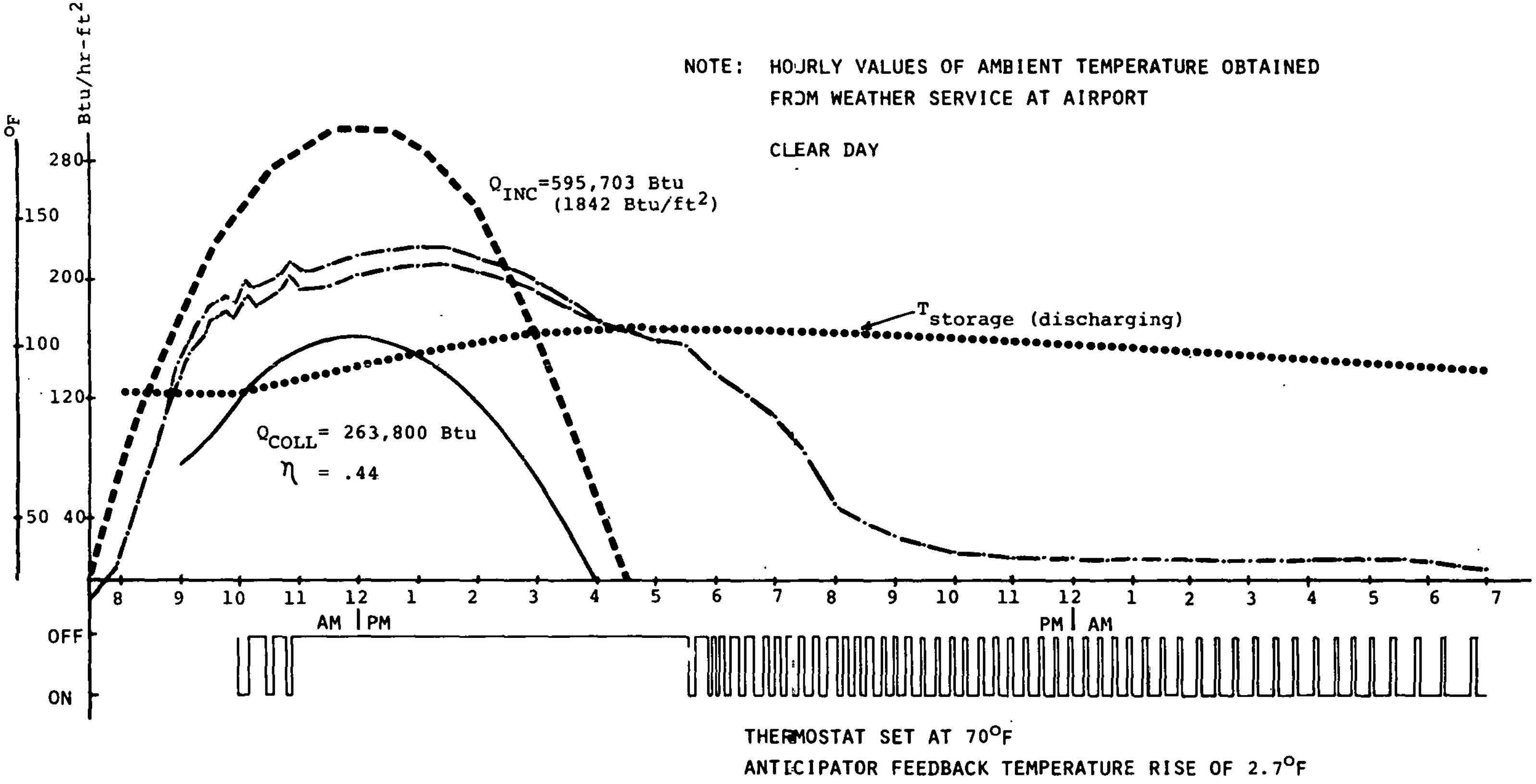
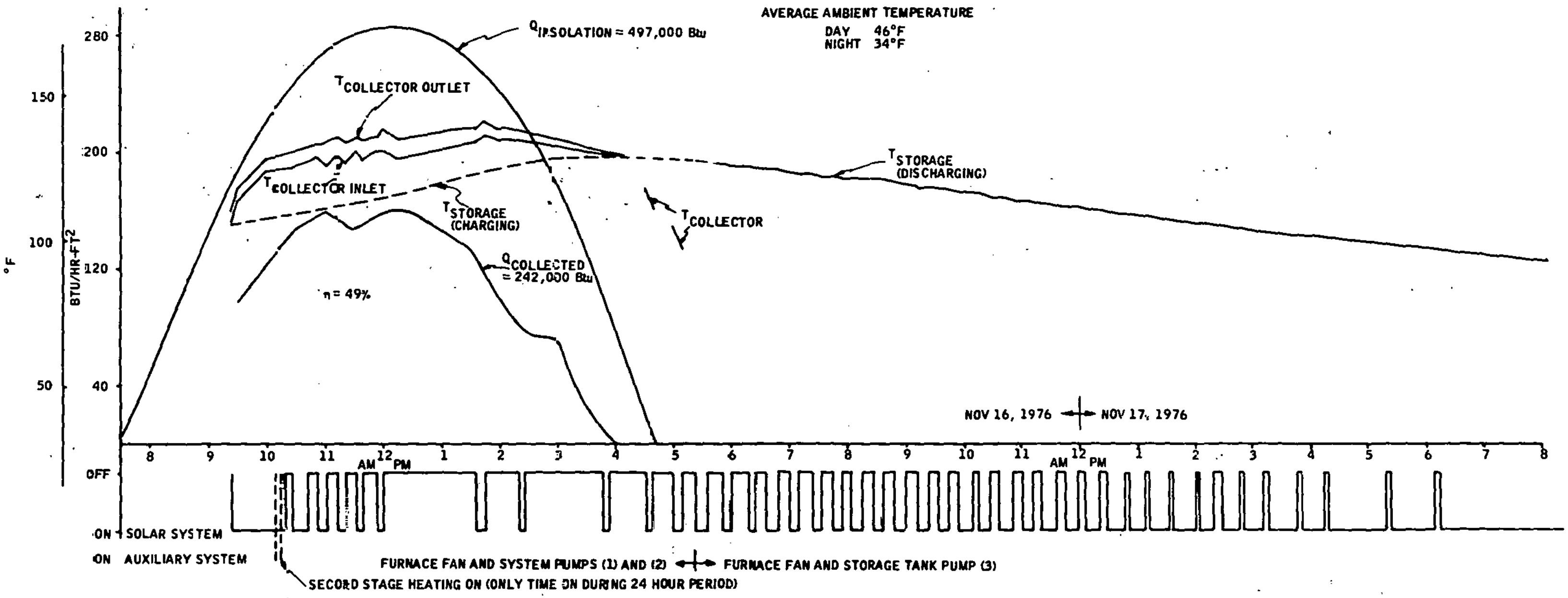


Figure E-31

EQUINOX SOLAR HEATING SYSTEM - 24 HOUR FIELD TEST

NOVEMBER 16-17, 1976



NOTES:
AVERAGE AMBIENT TEMPERATURE
DAY 46°F
NIGHT 34°F

Figure E-32

APPENDIX F
SOLAR HEATING/COOLING SYSTEM

INTRODUCTION

A solar heating/cooling system is defined as a basis for the comparative analysis of a solar alternate energy source and energy conservation techniques. The single basic design described is used on the analysis of all five building types and four geographic regions. The size of the solar system is changed with respect to component size to accommodate varying heating/cooling loads. Installed costs for both new and existing buildings are identified.

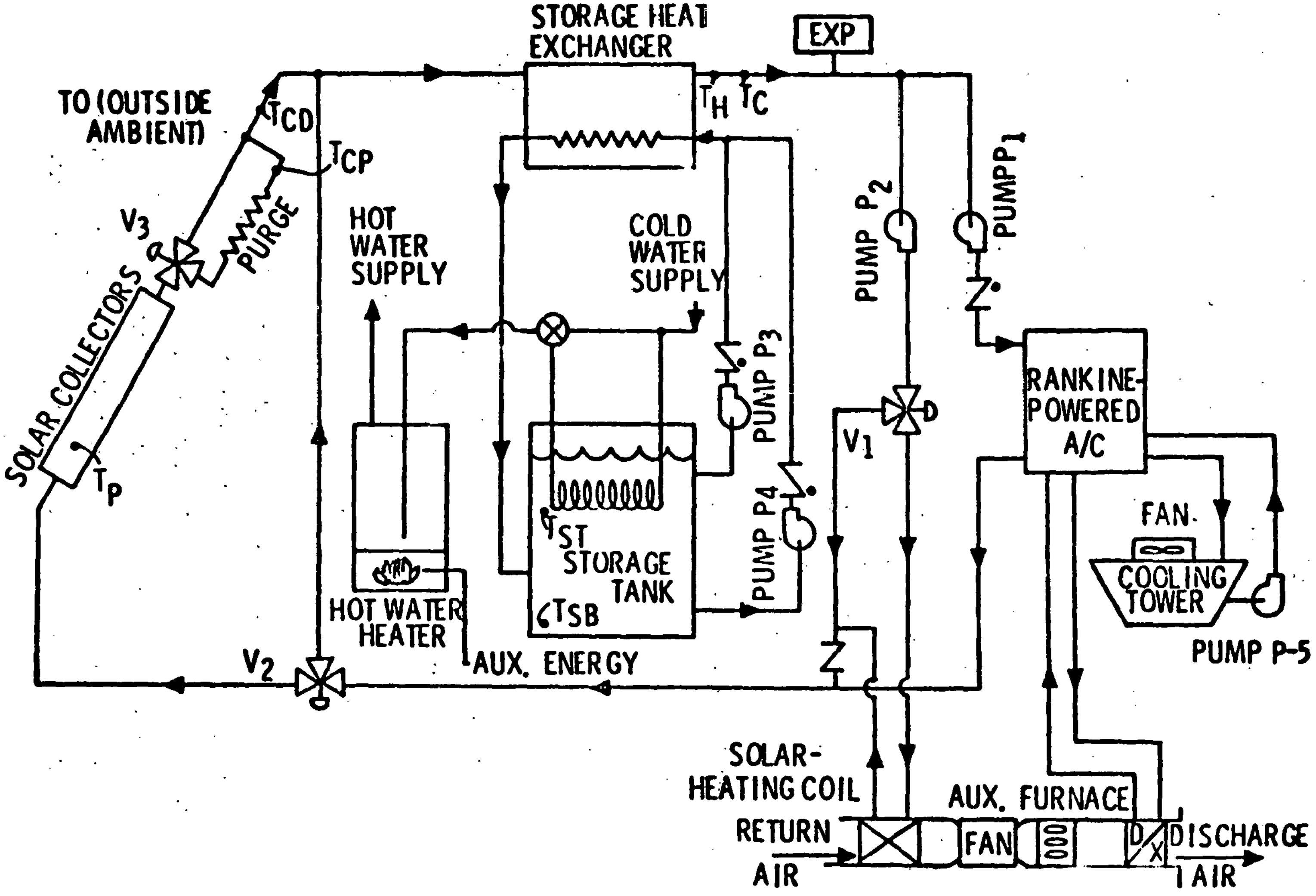
SYSTEM DESCRIPTION AND MAJOR COMPONENTS

The solar heating/cooling system is a single loop, solar assisted hydronic-to-warm air heating subsystem with solar-assisted domestic water heating and a Rankine-driven expansion air-conditioning subsystem. The system (depicted in Figure F-1) is composed of the following major components:

- Liquid Cooled Flat Plate Collectors--Collectors are the Honeywell/ Lennox design with two covers on panels. Collectors are connected in a series parallel configuration (two panels connected in series between parallel headers).

- Water Storage Tank--The capacity of the storage tank is 1.5 gallons per square foot of collector area. The tank is assumed insulated with 2" of polyurethane insulation and is located within new buildings and outside of existing buildings.

Figure F-1 Solar Heating/ Cooling System



- Passive Solar Fired Domestic Water Preheater--A domestic hot water preheat coil is located in the storage tank. Heat exchanger effectiveness is assumed to be one. The domestic hot water preheat coil, in combination with the storage heat exchanger, provides a double-wall separation between the ethylene gylcol/water solution in the collector loop and the potable domestic hot water system.

- Hot Water Heater--The size of the hot water tank is proportioned to building size. Sizes for the single-family residence, multi-family residence, retail store, school and office building are 40, 40(11), 40, 150, and 300 gallons, respectively. A limit mixing valve on the hot water tank limits the incoming water to 140°F. Auxiliary domestic hot water loads are calculated using fuel types of electricity, natural gas and oil.

- Warm Air Furnace with Hot Water Coil Unit--A forced air furnace is assumed for all installations. Auxiliary loads are calculated for all three fuel types, natural gas, electricity and fuel oil.

- Rankine-Driven Direct-Expansion Air-Conditionins with Auxiliary Electric Motor--The simulation assumes a three-ton unit for the single-family residence, a 25-ton unit for the multi-family residence, a 12-ton unit for the retail store, a 75-ton unit for the school and a 175-ton unit for the office building.

- Control System--Space heating and cooling is controlled by a two-stage heating and a single-stage cooling thermostat. First-stage heating supplies the auxiliary if solar is not adequate. System control logic provides for: 1) collecting solar energy when available; 2) supplying energy to the load on demand; 3) storing any excess energy; and 4) using solar energy before using auxiliary energy.

- Air-Cooled Heat Purge Unit -- The purge coil is located outside of the building and is used to protect other system components from over temperature. Excess heat is dumped via the purge unit.

SEQUENCE OF OPERATIONS

Heating Subsystem Operation

When solar energy is available and heating is required, the collectors supply heat directly to the furnace through the hot-water coil in the return air duct. Pump P_2 provides the heat-transfer fluid movement in this loop, and the furnace blower moves the building air through the heat coil. When the heating demand is satisfied, valve V_1 diverts the fluid around the hot-water coil and pump P_4 operates, charging the storage tank by removing water from the bottom, adding energy in the heat exchanger, and returning it to the center of the storage tank, thus taking advantage of stratification. During high solar radiation and low heating demand, both heating and storage loops operate simultaneously. If additional energy is still available, the purge coil operates, controlling the downstream temperatures to a preselected value.

When solar energy is not available and heating is required, storage supplies heat to the furnace through the heat exchanger. Pump P_2 drives the outside loop and pump P_3 extracts heat from the top of the storage tank and returns it to the center, again taking advantage of the tank stratification. If the storage tank temperature is not high enough to supply heating, the second-stage thermostat activates the auxiliary furnace until a comfortable temperature is maintained.

Cooling Subsystem Operation

When solar energy is available and cooling is required, the collectors supply heat directly to the Rankine boiler. Pump P_1 provides the heat-transfer fluid movement. The Rankine drives a high Coefficient-of-Performance (COP) compressor, which in turn, provides conventional direct-expansion cooling. When the cooling demand is satisfied, pump P_2 is shut down and the system reverts to the storage mode explained in the heating operation.

During high solar radiation and low cooling demand, simultaneous cooling and storage is available, using pump P_1 and pump P_4. If additional energy is still available, the purge coil operates by controlling the downstream temperatures to a preselected value. This is an infrequent mode and would occur if coils are oversized for a large heating demand.

When solar energy is not available or is insufficient to operate the Rankine engine at the design horsepower at 190°F collector outlet, an electric motor will operate the air conditioner independently or make up the difference between the required horsepower and that supplied by the R/C. Storage is used to supply energy in the same manner as in the heating operation, except that pump P_1 is the prime mover in the glycol/water loop. The baseline design uses a constant-speed compressor, and therefore, the electric motor is on-line at all times, supplying the balance of the required horsepower.

MODES OF OPERATION

The modes of operation are described below.

- First-Stage Heating From Collectors-- A demand for heat from the conditioned space activates the control system to first look for the energy in the collector, and through proper pump and valve selection, transfer the energy through the heating coil to the conditioned air. This mode involves valves V_1 and V_2, pump P_2, and the furnace fan.

Whenever plate temperature T_P is greater than 100°F and there is a call for heating from the space thermostat, pump P_2 is activated. Valve V_2 is positioned to direct flow to the collectors. Valve V_1 is positioned to direct flow through the heating coil. The furnace fan motor is activated whenever there is a heating command from the thermostat and fluid temperature entering the heating coil is greater than 100°F.

- Storage Charging While Heating-- If the solar radiation is more than adequate to provide the heating load, the excess energy can be added to storage by activating the storage charging loop. This mode involves the same components as the heating from the collectors plus pump P_4.

P_4 logic monitors excess energy ($T_H > 150°F$) and also determines that the bottom of the storage tank is at a lower temperature ($T_H - T_{SB} > 20°F$) activating the parallel storage mode.

- Charging Storage (Heating Season) -- With solar energy available and no demand for heating, the control system transfers the collector energy to the storage tank. This mode involves V_1, V_2, P_2 and P_4.

Storage charging is done whenever there is no call for heating when T_P is greater than 100°F, and when T_P is greater than T_{SB} by 20°F. Pumps P_2 and P_4 are activated. Valve V_2 is positioned to divert flow to the collectors as controlled by plate temperature T_P. Valve V_1 is positioned to divert flow around the heating coil.

- Heating From Storage -- As the availability of direct solar energy decreases and heating demand persists, the central system first looks to storage to satisfy the demand. This mode involves V_1, V_2, P_2, P_3 and the furnace fan.

Whenever T_P is less than 100°F, T_{ST} is greater than 100°F and there is a call for space heat, valve V_2 is positioned to divert flow around the collectors. Pump P_3 is activated to discharge heat from the storage tank for space heating. Pump P_2 is activated and valve V_1 is positioned to direct flow to the heating coil.

- Second Stage (Auxiliary) Heating-- When the solar heating system can no longer satisfy the load, the auxiliary furnace is ignited, providing heat in a conventional way.

- Direct Cooling from Collectors -- A demand for cooling from the conditioned space activates the control system to first look for energy in the collector and, through proper pump and valve selection, transfer the energy through the Rankine boiler. The Rankine engine supplies shaft power to the electric motor shaft to the level that the available solar energy allows. This mode involves V_2, P_1, furnace fan, cooling tower fan, and pump P_5.

Whenever plate temperature T_P is greater than 160°F and there is a call for cooling from space thermostat T_{SC}, pump P_1 discharges solar-heated fluid to the Rankine-cycle engine that drives the refrigeration compressor, providing cooling refrigerant to the furnace DX coil. Condenser water pump P_5 is energized, and the cooling tower fan is energized to run as controlled by a conventional thermostatic expansion valve at the cooling coil.

- Storage Charging While Cooling -- If the solar radiation is more than adequate to provide the cooling load, the excess energy can be added to storage by activating the storage charging loop. This mode involves the same components as the cooling from collectors plus pump P_4.

P_4 logic monitors excess energy ($T_C > 200°F$) and also determines that the bottom of the storage tank is at a lower temperature ($T_C - T_{SB} > 20°F$) and is activating the parallel storage mode.

- Charging Storage (Cooling Season) -- With solar energy available and no demand for cooling, the control system transfers the collector energy to the storage tank. This mode involves V_1, V_2, P_2, and P_4.

- Cooling From Storage-- As the availability of direct solar energy decreases and the cooling demand persists, the control first looks to storage to satisfy demand. This mode involves V_2, P_1, P_3, furnace fan, cooling tower fan, and pump P_5. Whenever T_P is less than 160°F, T_{ST} is greater than 160°F, and there is a call for space cooling, valve V_2 is positioned to divert flow around the solar collectors. Pump P_3 is activated to discharge heat from the storage tank to run the Rankine engine. All other functions and controls are similar to those for direct cooling.

Auxiliary Cooling -- Whenever there is a call for space cooling, the Rankine-cycle system is activated. The electric motor will supply the necessary energy for auxiliary cooling if solar-heated water is not available. It also supplies additional shaft power, if needed, during Rankine-cycle operation to assure a continuous output level.

COSTS

Installed solar system costs were examined with respect to fixed and variable costs for both new and existing buildings. This approach was selected since the analysis depended on the capability to assess the effect of variable collector area. Fixed and variable system components are identified in Table F-1. Costs of solar system are assumed constant for all four geographic regions.

Costs were also examined with respect to installation on both new and existing buildings. Installed costs were first determined for new buildings. For retrofit on existing buildings, additional costs were determined where installation was made more difficult and where additional structural support was deemed necessary. Costs are given for systems that provide heating, hot water, and air conditioning (H, HW, AC) as well as for systems providing only heating and hot water (H, HW).

Table F-1. Solar Heating/Cooling System Components

FIXED COMPONENTS

- Storage Tank and Insulation
- Solar Heating Coil in Furnace
- Auxiliary Forced Warm Air Furnace
- Domestic Hot Water Heater and Mixing Valve
- Storage Tank Heat Exchanger
- Solar Water Heat Exchanger
- Expansion Tank
- Purge Coil
- Pumps
- Check and Motorized Valves
- Controls
- Piping (Excluding Collector Piping) and Pipe Insulation
- Rankine Powered Air Conditioner
- Cooling Tower, Fan and Pump

VARIABLE COMPONENTS

- Collectors
- Piping on Collectors
- Collector Supports

Single Family Residence

New --

Installed costs for a new single family residence are represented by:

Installed costs = $10,166 + 17.85/FT^2$ (H, HW, AC)

or $6,035 + 17.85/FT^2$ (H, HW)

Existing --

Retrofit to the roof of an existing structure would require structural strengthening of roof structure, construction of supports to adjust the tilt angle, piping through areas that would have limited accessibility and integration into an existing furnace. Installed costs for an existing single family residence are represented by:

Installed Costs = $10,666 + 19.85/FT^2$ (H, HW, AC)

or $6,385 + 19.85/FT^2$ (H, HW)

Multi-Family Residence

New - -

Installed costs for a new multi-family residence are represented by:

Installed Costs = $83,007 + 25.80/FT^2$ (H, HW, AC)

or $63,755 + 25.80/FT^2$ (H, HW)

Existing--

Retrofit to the roof of an existing multi-family building would require structural strengthening of the roof structure, construction of supports to adjust the tilt angle, piping through areas of limited accessibility and integration into existing furnaces. Installed costs for an existing multi-family unit are represented by

Installed Costs = $85,507 + 27.80/FT^2$ (H, HW, AC)

or $65,755 + 27.80/FT^2$ (H, HW)

Retail Store

New--

Installed costs for a new retail store are represented by:

Installed Costs = 43,096 + 25.6/FT^2 (H, HW, AC)
or 28,047 + 25.6/FT^2 (H, HW)

Existing--

The existing retail store has a storage tank located outside the building. Additional costs are required for retrofitting solar system to an existing furnace. Installed costs are:

Installed Costs = 50,462 + 25.6/FT^2 (H, HW, AC)
or 32,519 + 25.6/FT^2 (H, HW)

Office Building

New--

Installed costs are represented by:

Installed Costs = 188,276 + 25.6/FT^2 (H, HW, AC)
or 80,276 + 25.6/FT^2 (H, HW)

Existing--

Additional costs are required for retrofitting the solar system to the office building. These costs are:

Installed Costs = 198,000 + 25.6/FT^2 (H, HW, AC)
or 90,000 + 25.6/FT^2 (H, HW)

School

New--

Installed costs are represented by:

Installed costs = 126,276 + 25.6/FT^2 (H, HW, AC)
or 79,776 + 25.6/FT^2 (H, HW)

Existing --

Additional costs are required for retrofitting the solar building with a solar system and integration into the existing HVAC system. These costs are:

Installed Costs = 136,276 + 25.6/FT^2 (H, HW, AC)
or 89,776 + 25.6/FT^2 (H, HW)

APPENDIX G
CONDENSED WEATHER

A computer program has been written that accesses an actual weather tape containing hourly weather data for a 365- or 366-day year. The program uses this data to prepare a condensed weather tape with a 36-day year. This 36-day tape can be used by simulation programs to accurately duplicate the results obtained when using an actual 365-366-day tape, but at about 1/10th the cost.

TAPE USAGE ALGORITHM

The condensed tape has 3 days for each of the 12 months (3*12=36; hence, the 36-day year). The first day of a month is a minimum day (characterized by low dry bulb temperatures and low solar insolation), the second day is a mean day (average temps and insolation), and the third day is a maximum day (high temps and insolation).

A simulation program that uses the tape reads in the first day's weather information and does all of its normal energy calculations, storing the results. Similarly, the second and third days of the tape are used as the weather inputs, and all of the program's normal calculations are performed.

The results of this 3-day month are then "scaled up" by the simulation program so that they are comparable to the results of an actual 30/31-day month. This is done by multiplying the first (minimum) day's results by the number of minimum days in the month, multiplying the second (mean) day's results by the number of mean days per month, and multiplying the third (maximum) day's results by the number of maximum days per month (the numbers of min, mean, and max days per month are given on the tape of the condensed yearly weather).

COMPARATIVE RESULTS

When the scaled-up results of the three days are totaled, the results are close to the monthly totals obtained by using an actual weather tape. with 30/31 days per month. Similarly, the yearly totals obtained by scaling-up the results of a 36-day tape are comparable to the results of an actual 365/366 day tape.

Tables G-1 and G-2 provide a detailed comparison of year-end totals obtained with a simulation program using an actual 365-day weather tape versus results obtained using a condensed 36-day tape.

Table G-1 summarizes the results of two representative runs of SUNSIM. Each run was done twice; one with the 365-day tape, and once with the 36-day tape. The numbers that are tabulated are the most important year-end totals that the simulation program displays.

Table G-2 summarizes the results of an economic analysis of the SUNSIM runs contained in Table G-1.

This comparison indicates a 36 day simulation will give adequate results for the purposes of this study.

Table G-1. Comparison of Year-End Energy Totals Produced by a Simulation Program Using 365-Day versus 36-Day Weather Tapes

	WITHOUT ECT			WITH ECT			
	365-Day	36-Day	% Diff	365-Day	36-Day	% Diff	
QHOUSE	266.9×10^6	266.3×10^6	-.2	240.8×10^6	240.5×10^6	-.1	Net house heating load
QAVAIL	0.5086×10^6	0.5241×10^6	3.0	0.5241×10^6	0.5241×10^6	3.0	Btus/ft**2 available to collector
QEXCES	0	0	0.0	0	0	0.0	Btus purged from system
QAUX	125.2×10^6	115.8×10^6	-7.5	108.1×10^6	100.1×10^6	-7.4	Space heat supplied by furnace
QSOL	141.7×10^6	150.5×10^6	6.2	132.7×10^6	140.4×10^6	5.8	Space heat supplied by solar
QHOUSS	198.9×10^6	190.0×10^6	-4.5	199.4×10^6	190.7×10^6	-4.4	Net house cooling load
WAUX	57.11×10^6	63.86×10^6	11.8	58.84×10^6	67.10×10^6	14.0	Watts for auxiliary cooling
QCSOL	59.25×10^6	49.88×10^6	-15.8	60.17×10^6	52.70×10^6	-12.4	Solar Btus into cooling
QHWATR	175.6×10^6	175.6×10^6	0.0	175.6×10^6	175.6×10^6	0.0	Hot water load
QHWAUX	96.67×10^6	97.86×10^6	1.2	95.79×10^6	96.08×10^6	3.0	Hot water supplied by conventional heater
QHWSOL	146.3×10^6	145.1×10^6	-.8	147.5×10^6	147.5×10^6	-.3	Hot water supplied by solar
QCOLL	441.7×10^6	443.8×10^6	.5	436.2×10^6	444.1×10^6	1.8	Btus collected

Table G-2. Comparison of Year-End Energy Cost Totals Produced by a Simulation Program Using 365-Day versus 36-Day Weather Tapes

	365-Day	36-Day	% Diff	365-Day	36-Day	% Diff
Gas	\$ 8918.86	\$ 8866.92	-.6	\$ 8856.85	\$ 8820.76	-.4
Electric	10143.38	10046.23	-1.0	9982.10	9903.60	-.8
Oil	9281.27	9215.94	-.7	9189.88	9141.23	-.5

DETAILED TAPE CONTENTS

The condensed tape consists of data for 36 words (days). Each day consists of seven 24-element real vectors (DB± DP± WB± WS± PB± CCFDIR± CCFTOT), one real value (NDAYTYPE), and four integers (year, month, day, city). An explanation of each element of a day on the condensed yearly weather tape follows.

DB = dry bulb temperature. DB has hourly and daily variation. The hourly DB values for the second (mean) day of a month correspond to the average hourly DB values for one month of actual data. The DB values for the first and third days of a month are found by subtracting or adding a statistically determined constant to the second day's DB values. Thus, the first and third days' DB curves have the same shape as the second day's curves, but they are displayed by a constant.

WB = wet bulb temperature. WB has hourly and daily variation. Once a DB value has been determined, WB is calculated using polynomial curve-fits of WB as a function of DB. WB is always less than or equal to DB.

DP = dew point temperature. DP has hourly and daily variation. Once DB, WB, and PB have been determined, DP is calculated using the ASHRAE psychrometric algorithms. DP is always less than or equal to WB.

WS = wind speed. A single value is used for an entire month. (Each month has a different value for WS). This value is the arithmetic average of the wind speed data for one month of actual data.

PB = pressure (barometric). A single value is used for an entire month. (Each month has a different value for PB.) This value is the arithmetic average of the barometric pressure data for one month of actual data.

CCFDIR and CCFTOT (see below) are calculated in an attempt to find average radiation. It was assumed that average cloud-modified radiation could be calculated fairly accurately by multiplying unmodified radiation by average CCF values.

CCFDIR = cloud cover factor (direct radiation). CCFDIR has hourly and daily variation. The CCFDIR values for the second (mean) day of a month correspond to the average hourly CCFDIR values for one month of actual data. The CCFDIR values for the first and third days of a month were found in the same way that the DB values were found.

CCFTOT = cloud cover factor (total radiation). CCFTOT has hourly and daily variation. The CCFTOT values are found in exactly the same way that the CCFDIR values were found.

NDAYTYPE = number of days of a certain type (min, mean or max). For example, if it is the first day of a month, NDAYTYPE equals the number of minimum days in that month.

Year = the year in which the actual data was measured.

Month = month of the year. "Month" = 1, 2, ... , 11, 12.

Day = day of the month. "Day" = 1, 2, or 3: 1 = min day, 2 = mean day, 3 = max day.

City = the 5-digit city code for the city in which the actual data was measured.

APPENDIX H

SINGLE-AND MULTI-FAMILY DWELLING CHARACTERISTICS AND ENERGY CONSERVATION TECHNIQUES

For

Honeywell, Inc.
Minneapolis, Minnesota

By

National Association of Home Builders

Research Foundation, Inc.

CONTENTS

INTRODUCTION

This report contains descriptions and characteristics of new and existing single-family detached dwellings and new low-rise multifamily dwelling units by four U. S. Census regions. Information on characteristics of existing multifamily dwelling units was not readily available and could not be developed within the time constraints of this report. Should reliable sources for data on existing multifamily dwelling units be discovered in the future, these sources and data will be submitted.

In addition to the characteristics data, prioritized lists of energy conservation techniques were developed according to three major zones of heating demand. Of course, these zones do not follow Census region boundaries.

NEW SINGLE-FAMILY DETACHED DWELLINGS

Data presented in this section were compiled primarily from a survey of almost 118,500 single-family dwellings conducted in 1975. It is probable that certain energy related characteristics have changed since that survey. A preliminary analysis of a 1976 survey now underway indicates that builders are using more insulation, more insulating glass windows and more storms doors and storm windows than in 1975. Also, there appears to be a switch from gas heat to electric and/or oil heat in some areas because of the inavailability of natural gas. These and other characteristic trends will be quantified sometime in the Spring of 1977.

The 1975 survey was aggregated by census region and all characteristic data contained herein are on a regional basis. Following is a breakdown of survey response by region.

Region	Number of Homes in 1975 Survey	Percent of Total
Northeast	14,253	13
North Central	26,081	22
South	49,337	41
West	28,797	24

The percentage of each region to the total survey is almost identical to the percentages of actual single-family detached housing starts reported by the U. S. Department of Commerce.

DESCRIPTIONS OF NEW SINGLE-FAMILY DETACHED DWELLINGS

Following are written descriptions of composite new single-family detached dwellings for each of the four census regions. Predominant characteristics were used to write the home descriptions. Therefore, these homes can be considered "typical" for the region. However, they may not be "typical" for certain localities within the region.

Descriptions of New Single-Family Detached Dwellings Which Incorporate Predominant Characteristics of All Single-Family Detached Homes in Region

Northeast

1560 square feet, one story on basement. Wood frame exterior wall, 1/2-inch plywood sheathing, wood siding, 1/2-inch gypsumboard interior surface. Three and one-half inch batt, R-11 wall insulation; 6-inch batt, R-19 ceiling insulation; no floor insulation. Wood frame floor with 5/8-inch plywood floor sheathing. No separate underlayment. Carpet finished floor. 198 square feet of window area with storm windows. 31 square feet of sliding glass door. 68 square feet of wood exterior doors without storm doors. Gas warm air furnace. No air conditioning.

North Central

1483 square feet, one story on basement. Wood frame exterior wall, 1/2-inch fiberboard sheathing, wood siding, 1/2-inch gypsumboard interior surface. Three and one-half inch batt, R-11 wall insulation; 6-inch loose fill, R-13 ceiling insulation; no floor insulation. Wood frame floor with 3/4-inch plywood sheathing. No separate underlayment. Carpet finished floor. 198 square feet of window area with storm windows. 26 square feet of sliding glass door. 76 square feet of wood exterior doors with storm doors. Gas warm air furnace. No air conditioning.

South

1647 square feet, one story on concrete slab. Wood frame exterior wall, 1/2-inch fiberboard sheathing, brick veneer exterior surface, 1/2-inch gypsumboard interior surface. Three and one-half inch batt, R-11 wall insulation; 6-inch loose fill, R-13 ceiling insulation; no slab perimeter insulation. Carpet finished floor. 208 square feet of window area without storm windows. 28 square feet of sliding glass door. 69 square feet of wood exterior doors without storm doors. Electric warm air furnace with air conditioning.

West

1577 square feet, one story on concrete slab. Wood frame exterior wall, no sheathing, stucco exterior surface, 1/2-inch gypsumboard interior surface. Three and one-half inch batt, R-11 wall insulation; 6-inch batt, R-19 ceiling insulation; no slab perimeter insulation. Carpet finished floor. 201 square feet of window area without storm windows. 34 square feet of sliding glass door. 63 square feet of wood exterior doors without storm doors. Gas warm air furnace with air conditioning.

Following is an analysis of the predominant characteristics for homes represented by the 1975 survey. Shown are the most common response to each characteristic and the percentage of new homes to which that response applies. In some cases, the most common response was not overwhelmingly popular. For example, one story houses in the Northeast represented only 35 percent of the total, with two story houses close behind at 33 percent; bi-levels, 25 percent; and split-levels, 7 percent.

Although the most common answer to ceiling insulation in the North Central region was 6-inch, R-13 loose fill, that answer represented only 35 percent of the houses in that region.

Typical New Single-Family Detached Dwellings by Percent of Predominant Characteristics by Region

CHARACTERISTIC	NORTHEAST	NORTH CENTRAL	SOUTH	WEST
Size - Square Feet	1560	1483	1647	1577
No. of Stories	One (35%)	One (49%)	One (72%)	One (65%)
Foundation Type	Bsmt. (82%)	Bsmt. (82%)	Slab (69%)	Slab (54%)
Fuel Type (Heating)	Gas (42%)	Gas (76%)	Elec. (65%)	Gas (66%)
Insulation R-Values				
● Exterior Walls	R-11 (92%)	R-11 (92%)	R-11 (73%)	R-11 (61%)
● Ceiling/Roof	R-19 (43%)	R-13 (35%)	R-13 (49%)	R-19 (44%)
● Floors (Wood)	None (55%)	None (77%)	R-11 (53%)	None (84%)
Exterior Wall Construction	Wood (95%)	Wood (99%)	Wood (84%)	Wood (86%)
Exterior Wall Finish	Wood (35%)	Wood (41%)	Masonry (71%)	Masonry (54%)
Exterior Wall Sheathing	1/2" P.W. (35%)	1/2" F.B. (71%)	1/2" F.B. (46%)	None (37%)
P.W. = Plywood F.B. = Fiberboard				
Interior Wall Finish				
Gyp. = Gypsumboard	1/2" Gyp. (75%)	1/2" Gyp. (85%)	1/2" Gyp. (86%)	1/2" Gyp. (90%)
Wood Floor Sheathing	5/8" P.W. (45%)	3/4" P.W. (38%)	1/2" P.W. (37%)	5/8" P.W. (35%)
P.W. = Plywood				
Wood Floor Underlayment				
P.W. = Plywood P.B. = Particleboard H.B. = Hardboard	None (48%) 5/8" P.B. (24%)	None (46%) 5/8" P.B. (26%)	None (40%) 5/8" P.B. (32%)	None (35%) 5/8" P.B. (26%)
Finish Floor	Carpet (53%)	Carpet (76%)	Carpet (72%)	Carpet (74%)

Typical New Single-Family Detached Dwellings by Percent (CONTINUED)

CHARACTERISTIC	NORTHEAST	NORTH CENTRAL	SOUTH	WEST
Exterior Glass (Windows) S = Single, No Storms S.S. = Single With Storms	S.S. (43%)	S.S. (48%)	S (75%)	S (81%)
Exterior Doors	Wood (60%)	Wood (63%)	Wood (81%)	Wood (86%)
Storm Doors	No (60%) Yes (40%)	Yes (55%) No (45%)	No (61%) Yes (39%)	No (62%) Yes (38%)

The following characteristics of new single-family detached dwellings contains some "weighted" average values for certain characteristics. The weighting was done to determine the overall characteristics of all new homes within a region rather than to develop a "typical" house.

For example, the weighted average R-value of exterior walls in new homes in the North Central region is R-13.7 -- R-10.8 insulation plus R-2.9 for other wall materials.

Characteristics of New Single-Family Detached Dwellings by Region

CHARACTERISTIC	NORTHEAST	NORTH CENTRAL	SOUTH	WEST
Size - Square Feet	1560	1483	1647	1577
No. of Stories	1.5	1.3	1.1	1.2
First Floor and Ceiling SF	1068	1144	1452	1329
Second Floor SF	492	339	195	348
Foundation Types				
• Basement and Partial Basement	82%	82%	18%	24%
• Concrete Slab	7%	9%	69%	54%
• Crawl Space	11%	9%	13%	22%
Heating Fuel Type				
• Gas	42%	76%	31%	66%
• Oil	26%	2%	2%	3%
• Electric	32%	22%	65%	31%
Insulation R-Values				
• Walls (Exterior)	R-10.0	R-10.8	R-8.8	R-8.0
• Ceiling/Roof	R-17.9	R-16.1	R-15.0	R-15.9
• Wood Floors	R-4.8	R-3.9	R-6.6	R-1.8
Other Material R-Values				
• Walls (Exterior)	R-2.5	R-2.9	R-2.7	R-2.5
• Ceiling/Roof	R-1.7	R-1.7	R-1.7	R-1.7
• Wood Floors	R-4.0	R-4.2	R-4.2	R-4.4

Characteristics of New Single-Family Detached Dwellings by Region (CONTINUED)

CHARACTERISTIC	NORTHEAST	NORTH CENTRAL	SOUTH	WEST
Exterior Wall Construction				
• Wood Frame	95%	99%	84%	86%
• Solid Masonry	4%	1%	12%	10%
• Other	1%	0%	4%	4%
Exterior Wall Finish				
• Masonry, including stucco, solid masonry and masonry veneer	16%	25%	71%	54%
• Wood, including plywood, hardboard, wood shakes and wood board	35%	41%	23%	43%
• Metal	29%	31%	4%	2%
• Other, including asbestos and vinyl	20%	3%	2%	1%
Exterior Glass Area Square Feet				
• Single glazing (no storms)	66	51	156	163
• Single glazing with storms	86	95	24	7
• Insulating glass windows	46	52	28	31
• Sliding glass doors	31	26	28	34
Total Glass Area =	229 SF	224 SF	236 SF	235 SF
Glass Area as Percent of Floor Area	14.7%	15.1%	14.3%	14.9%

Characteristics of <u>New</u> Single-Family Detached Dwellings by Region (CONTINUED)

CHARACTERISTIC	NORTHEAST	NORTH CENTRAL	SOUTH	WEST
Exterior Doors (Type by Square Feet)				
● Wood	41	48	56	54
● Insulating Metal	27	28	13	9
Storm Doors (Square Feet)	27	42	27	24

EXISTING SINGLE-FAMILY DETACHED DWELLINGS

Data presented in this section represents the entire existing single-family detached housing inventory in each region. These data were obtained and compiled from several sources, including the U. S. Census Bureau, a 1972 survey of builder practices and a 1975 in-depth survey of new home construction.

Because the different sources presented data in different formats, interpolation was used where necessary. Also, estimates were sometimes used based on an overview of the known information and on knowledge of the approximate time frame that certain products came into the residential construction market.

Information on remodeling or addition characteristics was not available in a useful format, so the existing single-family detached data does not contain allowances for remodeling or additions.

The existing single-family detached housing inventory is broken into the following age groups.

Dwelling Age Group		Number of Dwellings	Percent of Total
Before 1940		16,000,000	31.2
1940 - 1949		6,252,000	12.2
1950 - 1959		12,867,000	25.1
1960 - 1969		9,240,000	18.0
1970 - 1975		6,903,000	13.5
	Total	51,262,000	100.0

DESCRIPTIONS OF EXISTING SINGLE-FAMILY DETACHED DWELLINGS

The following written descriptions of existing single-family detached dwellings were compiled from predominant characteristics of all homes within each region. Therefore, these homes can be considered "typical" of all houses within the region, but may not be typical for certain localities within the region.

Descriptions of Existing Single-Family Detached Dwellings Which Incorporate Predominant Characteristics of All Single-Family Detached Homes in Region

Northeast

1225 square feet, one story on basement. Wood frame exterior wall, wood sheathing, wood siding, plaster interior surface. No exterior wall insulation; 4-inch loose fill, R-9 ceiling insulation, no floor insulation. Wood frame floor with hardwood finished floor. 174 square feet of window area without storm windows. 13 square feet of sliding glass door. 56 square feet of wood exterior doors. No storm doors. Gas boiler hot water baseboard heat. No air conditioning.

North Central

1177 square feet, one story on basement. Wood frame exterior wall, wood sheathing, wood siding, plaster interior surface. No exterior wall insulation; 4-inch loose fill, R-9 ceiling insulation, no floor insulation. Wood frame floor, wood sheathing, hardwood finished floor. 177 square feet of window area without storm windows. 12 square feet of sliding glass door. 63 square feet of wood exterior doors without storm doors. Gas warm air furnace. No air conditioning.

South

1213 square feet, one story on crawl space. Wood frame exterior wall, wood sheathing, brick veneer exterior surface, 1/2-inch gypsumboard interior surface. No wall, ceiling or floor insulation. Wood frame floor with hardwood finished floor. 163 square feet of window area without storm windows. 13 square feet of sliding glass door. 59 square feet of wood exterior door. Gas warm air furnace. Window air conditioning unit.

West

1237 square feet, one story on crawl space. Wood frame exterior wall, no sheathing, stucco exterior surface, plaster interior surface. No wall, ceiling or floor insulation. Wood frame floor, wood sheathing, carpet finished floor. 175 square feet of window area without storm windows. 17 square feet of sliding glass door. 54 square feet of wood exterior door. No storm doors. Gas warm air furnace. No air conditioning.

The following characteristics of existing single-family detached dwellings were weighted by the number of dwellings in each age group. Weighting was done to determine overall characteristics of all existing homes within a region rather than to develop a "typical" house.

Characteristics of Existing Single-Family Detached Dwellings by Region

CHARACTERISTIC	NORTHEAST	NORTH CENTRAL	SOUTH	WEST
Size - Square Feet	1225	1177	1213	1237
No. of Stories	1.4	1.2	1.1	1.1
First Floor and Ceiling Square Feet	735	942	1092	1113
Second Floor Square Feet	490	235	121	124
Foundation Types				
• Basement and Partial Basement	83%	59%	19%	19%
• Concrete Slab	6%	11%	34%	35%
• Crawl Space	11%	30%	47%	46%
Heating Fuel Type				
• Gas	49%	73%	71%	84%
• Oil	40%	20%	14%	5%
• Electric	7%	7%	15%	10%
• Coal	2%	-	-	-
• Other	2%	-	-	1%
Insulation R-Values				
• Exterior Walls	R-6.6	R-5.6	R-3.3	R-2.4
• Ceiling/Roof	R-13.4	R-11.9	R-9.2	R-10.0
• Wood Floors	R-0.9	R-0.9	R-1.3	R-0.6

Characteristics of Existing Single-Family Detached Dwellings by Region (CONTINUED)

CHARACTERISTIC	NORTHEAST	NORTH CENTRAL	SOUTH	WEST
Other Material R-Values				
• Exterior Walls	R-2.5	R-2.9	R-2.7	R-2.5
• Ceiling/Roof	R-1.7	R-1.7	R-1.7	R-1.7
• Wood Floors	R-4.0	R-4.2	R-4.2	R-4.4
Exterior Wall Construction				
• Wood Frame	94%	99%	84%	86%
• Solid Masonry	5%	1%	12%	10%
• Other	1%	0%	4%	4%
Exterior Wall Finish				
• Masonry	14%	24%	61%	48%
• Wood	37%	54%	27%	46%
• Metal	14%	14%	2%	3%
• Other	35%	8%	10%	3%
Exterior Glass Area Square Feet				
• Single glazing (no storms)	116	109	149	167
• Single glazing with storms	47	56	10	3
• Insulating glass windows	11	12	4	5
• Sliding glass doors	13	12	13	17
Total Glass Area =	187	189	186	192

Characteristics of Existing Single-Family Detached Dwellings by Region (CONTINUED)

CHARACTERISTIC	NORTHEAST	NORTH CENTRAL	SOUTH	WEST
Glass Area as Percent of Floor Area	15.3%	16.1%	15.3%	15.5%
Exterior Doors (Type by SF)				
• Wood	49	56	55	51
• Insulating Metal	7	7	4	3
Storm Doors (Square Feet)	15	20	15	10

NEW MULTIFAMILY LOW-RISE DWELLINGS

Data presented in this section were compiled primarily from two NAHB Research Foundation surveys of apartments built in 1970 and 1975. As with single-family detached dwellings, it is probable that certain energy related characteristics have changed since those surveys. A new survey is being conducted which will update all low-rise multifamily characteristic data. Results of this survey will be compiled in the Spring of 1977.

DESCRIPTIONS OF NEW MULTIFAMILY LOW-RISE DWELLING UNITS

The following descriptions of new low-rise multifamily units incorporate the predominant characteristics of all new units within each region. Therefore, the descriptions can be considered "typical" apartment units for the region although they may not be "typical" for certain localities within the region.

Descriptions of New Multifamily Dwellings Which Incorporate Most Predominant Characteristics of All Multifamily Low-Rise Units in Region

Northeast

880 square feet per living unit. Two story building on basement. Four units per floor serviced by one stairway. Wood frame exterior wall, 1/2-inch fiberboard sheathing, brick veneer exterior surface, 1/2-inch gypsumboard interior surface. Three and one-half inch batt, R-11 wall insulation; 6-inch loose fill, R-13 ceiling insulation; no floor insulation. Wood frame floor with 5/8-inch plywood sheathing. No separate underlayment. Carpet finished floor. 63 square feet of insulating glass windows. 38 square feet of sliding glass door. 20 square feet of insulating metal entrance door. Gas central boiler with hot water baseboard heat. Window or through wall cooling.

North Central

860 square feet per living unit. Two story building on basement. Four units per floor serviced by one stairway. Wood frame exterior wall, 1/2-inch fiberboard sheathing, brick veneer exterior surface, 1/2-inch gypsumboard interior surface. Three and one-half inch batt, R-11 wall insulation; 6-inch loose fill, R-13 ceiling insulation; no floor insulation. Wood frame floor with 5/8-inch plywood sheathing. No separate underlayment. Carpet

finished floor. 66 square feet of insulating glass windows. 35 square feet of sliding glass door. 20 square feet of insulating metal entrance door. Gas individual unit warm air furnace. Individual unit air conditioning, combined with furnace.

South

900 square feet per living unit. Two story building on concrete slab. Four units per floor serviced by one stairway. Wood frame exterior wall, 1/2-inch gypsumboard sheathing, brick veneer exterior surface, 1/2-inch gypsumboard interior surface. Three and one-half inch batt, R-11 wall insulation; 6-inch loose fill, R-13 ceiling insulation; no floor insulation. Wood frame upper floor with 5/8-inch plywood sheathing. No separate underlayment. Carpet finished floor. 68 square feet of single glazed windows without storms. 36 square feet of sliding glass door. 20 square feet of wood entrance door. Gas individual unit warm air furnace. Individual unit air conditioning, combined with furnace.

West

910 square feet per living unit. Two story building on concrete slab. Two units per floor serviced by one stairway. Wood frame exterior wall, no exterior sheathing, stucco exterior wall surface, 1/2-inch gypsumboard interior wall surface. Three and one-half inch batt, R-11 wall

insulation, 6-inch batt, R-19 ceiling insulation, no floor insulation. Wood frame upper floor with 5/8-inch plywood sheathing. No separate underlayment. Carpet finished floor. 65 square feet of single glazed windows without storms. 36 square feet of sliding glass door. 20 square feet of wood entrance door. Electric baseboard heating. Window or through wall cooling.

Following is an analysis of predominant low-rise multifamily dwelling unit characteristics. Shown are most common responses for each characteristic and the percentage of new units to which the response applies. In some cases, the most common response was not overwhelmingly popular. For example, the most common answer to ceiling/roof insulation in the North Central region, R-13 loose fill insulation, represented only 34 percent of all units within that region.

Typical New Low-Rise Multifamily Dwellings by Most Predominant Characteristics by Region

CHARACTERISTIC	NORTHEAST	NORTH CENTRAL	SOUTH	WEST
Size - Square Feet	880	860	900	910
Stories/Building	Two (91%)	Two (83%)	Two (87%)	Two (91%)
Foundation Type	Bsmt. (69%)	Bsmt. (51%)	Slab (69%)	Slab (53%)
Heating Fuel Type	Gas (55%)	Gas (76%)	Gas (58%)	Elec. (56%)
Units/Floor/Stair	Four (50%)	Four (53%)	Four (46%)	Two (68%)
Insulation R-Values				
● Exterior Walls	R-11 (87%)	R-11 (92%)	R-11 (88%)	R-11 (87%)
● Ceiling/Roof	R-13 (39%)	R-13 (34%)	R-13 (50%)	R-19 (49%)
● Floors (Wood)	None (59%)	None (56%)	None (67%)	None (68%)
Exterior Wall Construction	Wood (60%)	Wood (63%)	Wood (52%)	Wood (94%)
Exterior Wall Finish	Masonry (67%)	Masonry (63%)	Masonry (68%)	Masonry (50%)
Exterior Wall Sheathing	1/2" F.B. (39%)	1/2" F.B. (67%)	1/2" Gyp. (36%)	None (34%)
F.B. = Fiberboard Gyp. = Gypsumboard			None (36%)	
Interior Wall Finish	1/2" Gyp. (82%)	1/2" Gyp. (97%)	1/2" Gyp. (97%)	1/2" Gyp. (95%)
Gyp. = Gypsumboard				
Wood Floor Sheathing	5/8" PW (51%)	5/8" PW (36%)	5/8" PW (46%)	5/8" PW (49%)
PW = Plywood				
Wood Floor Underlayment	None (77%)	None (62%)	None (77%)	None (72%)
Finish Floor	Carpet (81%)	Carpet (100%)	Carpet (91%)	Carpet (85%)
Exterior Glass (Windows)	Insul (60%)	Insul (62%)	S (91%)	S (91%)
Insul = insulating glass S = single, no storms				

Typical New Low-Rise Multifamily Dwellings (CONTINUED)

CHARACTERISTIC	NORTHEAST	NORTH CENTRAL	SOUTH	WEST
Exterior Doors	Metal (60%)	Metal (55%)	Wood (75%)	Wood (65%)
Heating System	CB (50%)	IWA (49%)	IWA (60%)	EBB (38%)
CB = Central boiler IWA = Individual warm air EBB = Electric baseboard				
Cooling System	Win. (72%)	Ind. (50%)	Ind. (68%)	Win. (63%)
Win. = Window or through wall unit Ind. = Individual unit in conjunction with furnace				

The following table of new low-rise multifamily characteristics contains some "weighted" values. That is, the characteristics were weighted according to the survey responses. For example, the weighted average low-rise multifamily dwelling exterior wall insulation in the Northeast is R-10.4.

Characteristics of New Low-Rise Multifamily Dwellings by Region

CHARACTERISTIC	NORTHEAST	NORTH CENTRAL	SOUTH	WEST
Size - Square Feet	880	860	900	910
No. Stories/Building	2.2	2.4	2.3	2.2
Foundation Types				
● Basement and Partial Basement	69%	51%	22%	25%
● Concrete Slab	25%	44%	69%	53%
● Crawl Space	6%	5%	9%	22%
Heating Fuel Type				
● Gas	55%	76%	58%	44%
● Oil	21%	6%	5%	0
● Electric	24%	18%	37%	56%
Insulation R-Values				
● Exterior Walls	R-10.4	R-10.8	R-7.8	R-10.4
● Ceiling/Roof	R-19.1	R-17.3	R-16.8	R-18.5
● Wood Floors	R-6.3	R-3.7	R-2.7	R-3.7
Other Material R-Values				
● Walls (Exterior)	R-3.0	R-3.0	R-3.0	R-2.8
● Ceiling/Roof	R-1.7	R-1.7	R-1.7	R-1.7
● Wood Floors	R-4.0	R-4.2	R-4.2	R-4.4

Characteristics of New Low-Rise Multifamily Dwellings by Region (CONTINUED)

CHARACTERISTIC	NORTHEAST	NORTH CENTRAL	SOUTH	WEST
Exterior Wall Construction				
● Wood Frame	60%	63%	52%	94%
● Solid Masonry	38%	36%	46%	0
● Other	2%	1%	2%	6%
Exterior Wall Finish				
● Masonry	62%	63%	68%	50%
● Wood	22%	24%	28%	42%
● Metal	10%	10%	2%	4%
● Other	6%	3%	2%	4%
Exterior Glass Area Square Feet				
● Single glazing* (no storms)	25	25	62	59
● Insulating glass windows	38	41	6	6
● Sliding glass doors	38	35	36	36
Total Glass Area =	101 SF	101 SF	104 SF	101 SF
Glass Area as Percent of Floor Area	11.5%	11.7%	11.6%	11.1%
Unit Entrance Door - Type by SF				
● Wood	7	9	15	13
● Insulating Metal	13	11	5	7

(No data available on multifamily storm doors)

*No data available for multifamily storm windows

Following are selected pages from an NAHB Research Foundation survey of low-rise multifamily dwellings. Responses usually add up to more than 100 percent because of multiple answers. For use in developing characteristic data, all responses were recalculated to add to 100 percent.

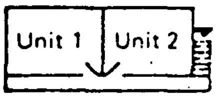
Apartment 70's : LOW-RISE APARTMENT SURVEY

TABLE 1. BASIC APARTMENT TYPE

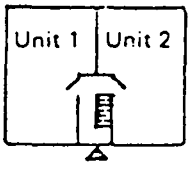
	PERCENT OF RESPONDENTS* REGIONS				
DESIGN TYPE	NORTH-EAST	NORTH CENTRAL	SOUTH	WEST	ALL REGIONS
D	28	32	19	18	25
C	15	22	26	12	23
B	17	12	26	64	22
Other (H)	24	22	15	0	17
G	6	15	4	0	8
A	4	2	11	0	6
F	7	4	7	0	5
E	0	1	5	0	3

Low rise apartment builders utilize a wide variety of basic apartment designs. Three types (D, C, B) predominate, see below. They are: Two units on the same level with a common entrance; four units on the same level with one common entrance; and four units on the same level with two entrances and a short hallway. Nearly three-fourths of all respondents used these types. About one-sixth of the respondents indicated that they used "other" designs. Design types used in the West are substantially different than the average.

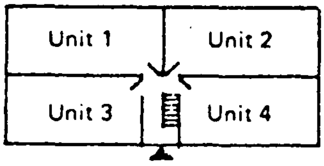
☐A.



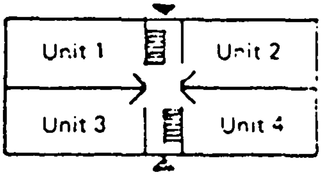
☐B.



☐C.



☐D.



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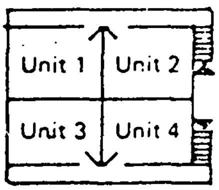

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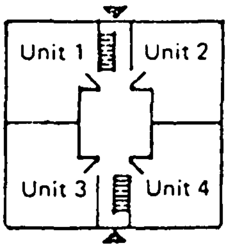
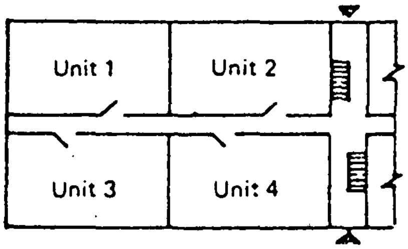


☐G.



☐H. Sketch Other Type

* PERCENTAGES do not necessarily equal 100 due to multiple answers.

Apartment 70's: LOW-RISE APARTMENT SURVEY

TABLE 2. NUMBER OF APARTMENT UNITS

	AVERAGE FREQUENCY				
	REGIONS				
	NORTH-EAST	NORTH CENTRAL	SOUTH	WEST	ALL REGIONS
Units per project	170	190	200	100	180
Units per acre	15	16	20	23	19
Units per building	14	20	15	16	16
Buildings per project	12	10	13	6	11

The data contained in this study are representative of builder respondents who constructed over 70,000 apartment units. The units were contained in 4,100 separate buildings and required a total of 7,900 acres of land. The average project contained 180 units in 11 buildings and was built on 9.5 acres (19 units per acre). In the North Central region there are more units per building. Southern builders build projects with the most number of units. Western builders build smaller projects but they have a higher density (units per acre).

Apartment 70's: LOW-RISE APARTMENT SURVEY

TABLE 3. AVERAGE NUMBER OF STORIES

	REGIONS				
	NORTH-EAST	NORTH CENTRAL	SOUTH	WEST	ALL REGIONS
Average Number	2.2	2.4	2.3	2.2	2.3

The number of stories varied widely from one to four with many builders indicating half stores due to hillside designs. On the average, the number of stories was 2.3.

Apartment 70's: LOW-RISE APARTMENT SURVEY

TABLE 4. FLOOR AREA PER UNIT

	AVERAGE SQUARE FEET				
	REGIONS				
	NORTH-EAST	NORTH CENTRAL	SOUTH	WEST	ALL REGIONS
Three-Bedroom Unit	1260	1230	1250	1160	1230
Two-Bedroom Units	960	950	990	1000	970
One-Bedroom Unit	750	700	820	890	780
Efficiency Unit	530	570	520	470	530
Average All Units	880	860	900	910	880

The average square feet for all units is 880. This is the living unit only and does not include entranceways, hallways, or any other areas used in common by tenants. The average three-bedroom unit is 1230 square feet and is over twice that of efficiency units, which average 530 square feet. Unit size tends to be the same throughout the nation with apartments in the South and West tending to be slightly larger.

Apartment 70's : LOW-RISE APARTMENT SURVEY

TABLE 5. FOUNDATION TYPE

*PERCENT OF RESPONDENTS**

REGIONS

	NORTH-EAST	NORTH CENTRAL	SOUTH	WEST	ALL REGIONS
Slab-On-Grade	26	49	74	64	59
Full Basement	44	32	10	12	22
Partial Basement	28	24	13	18	19
Crawl Space	7	6	10	27	9
Other	4	5	2	0	3

Most apartment builders build their units with a slab-on-grade foundation (fifty-nine percent). About 40 percent install either a full or partial basement. A much smaller number of builders use a crawl space. Variance by region is rather great. Full or partial basements predominate in the North East and North Central regions. In the South, slab-on-grade is used by three-fourths of the builders. In the West, some builders (27 percent) use a crawl space, but most (64 percent) use a slab-on-grade. The number of apartment units built on a slab-on-grade foundation appears to be higher than for single family homes.

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* PERCENTAGES do not necessarily equal 100 due to multiple answers.

Apartment 70's: LOW-RISE APARTMENT SURVEY

TABLE 6. EXTERIOR WALL STRUCTURE

	PERCENT OF RESPONDENTS* REGIONS				
	NORTH-EAST	NORTH CENTRAL	SOUTH	WEST	ALL REGIONS
Wood Frame	65	71	54	94	64
Brick Veneer Over Block	30	24	26	0	24
Concrete Masonry	6	8	13	0	9
Load-Bearing Brick	6	9	9	0	8
Other	2	1	2	6	2

Wood framing is the predominant exterior wall structure. This is true for all regions of the country. In the South, however, nearly as many builders use some type of masonry as do wood framing. The next most popular exterior wall systems are brick veneer over block (24 percent), concrete masonry (9 percent) and load-bearing brick (8 percent).

* PERCENTAGES do not necessarily equal 100 due to multiple answers.

Apartment 70's : LOW-RISE APARTMENT SURVEY

TABLE 7. FLOOR STRUCTURE

	PERCENT OF RESPONDENTS* REGIONS				
	NORTH-EAST	NORTH CENTRAL	SOUTH	WEST	ALL REGIONS
Wood Joists	87	85	77	88	81
Reinforced Concrete	0	11	15	9	11
Precast Concrete System	4	9	8	9	8
Wood Beams	19	5	3	15	6
Steel Bar Joists	0	2	3	3	2
Others	0	6	2	3	3

Wood joist or beam floor systems are used by seven out of eight apartment builders. However, a variety of other structural floor systems are used. Eleven percent of the respondents utilize reinforced concrete, 8 percent use precast concrete panels, and 2 percent use bar joists. There is only modest regional variation in the pattern of use. Wood beams are used much more frequently in the Northeast and the West. In the South, wood joists occur somewhat less frequently, and reinforced concrete somewhat more often than the average.

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* PERCENTAGES do not necessarily equal 100 due to multiple answers.

Apartment 70's : LOW-RISE APARTMENT SURVEY

TABLE 9. ROOF TYPE

*PERCENT OF RESPONDENTS**
REGIONS

	NORTH-EAST	NORTH CENTRAL	SOUTH	WEST	ALL REGIONS
Gable	52	50	61	48	55
Flat	28	15	30	55	32
Mansard	22	32	26	27	28
Hip	26	21	17	12	19
Other	2	2	0	0	1

Many builders build apartments with more than one type of roof. Most roofs, however, are either gable or flat. Fewer flat roofs are used in the Northeast and North Central regions, and more are used in the West. When commenting on problems and plans for change, many builders named leaky flat roofs and indicated that they are not going to use them in the future.

* PERCENTAGES do not necessarily equal 100 due to multiple answers.

Apartment 70's: LOW-RISE APARTMENT SURVEY

TABLE 16. ROOFING MATERIAL

*PERCENT OF RESPONDENTS**

REGIONS

	NORTH-EAST	NORTH CENTRAL	SOUTH	WEST	ALL REGIONS
Asphalt Strip Shingles	63	68	71	36	67
Built-Up Roof	33	37	43	61	41
Wood (Shakes or Shingles)	2	10	9	30	10
Other	4	1	1	3	1

Most builders use asphalt strip shingles. About two-fifths use built-up roofing with the highest concentration of use being in the West as expected where flat roofs predominate. Wood shake or shingle use is concentrated in the West (30 percent) and to a lesser extent in the North Central (10 percent) and Southern (9 percent) regions.

* PERCENTAGES do not necessarily equal 100 due to multiple answers.

TABLE 17. TYPE OF WINDOWS

	PERCENT OF RESPONDENTS* REGIONS				
	NORTH-EAST	NORTH CENTRAL	SOUTH	WEST	ALL REGIONS
Aluminum	70	82	90	100	87
Wood	26	19	11	0	15
Vinyl-Clad Wood	4	5	1	0	3
Steel	4	1	2	0	2

Aluminum frame windows predominate in the construction of apartments. Nearly 90 percent of the builders use this type. Aluminum frame windows are used virtually exclusively in the West and are the dominant type in all regions. Wood frame windows are used by 26 percent of the builders in the Northeast and by 19 percent in the North Central region.

* PERCENTAGES do not necessarily equal 100 due to multiple answers.

TABLE 18. EXTERIOR WALL FINISH

	PERCENT OF RESPONDENTS*				
	REGIONS				
	NORTH-EAST	NORTH CENTRAL	SOUTH	WEST	ALL REGIONS
Brick Veneer	78	95	85	18	84
Stucco	2	8	19	58	16
Plywood	6	16	17	27	16
Wood Shakes or Shingles	7	14	10	12	11
Aluminum	13	16	2	6	8
Wood Lap Siding	11	6	8	21	8
Hardboard	4	4	9	3	6
Concrete Block	0	2	2	0	2
Other	9	6	3	6	5

Brick veneer predominates as the exterior wall finish in all regions except the West, where it is used sparingly. Stucco is used to the greatest extent in the West, where it is the most common exterior wall finish. Two other exterior finishes, plywood and wood lap siding, are used most often in the West. Surprisingly, wood shake and shingle use as siding is most frequent in the North Central region. Aluminum siding use is concentrated mainly in the North Central (16 percent) and Northeastern regions (13 percent).

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* PERCENTAGES do not necessarily equal 100 due to multiple answers.

Apartment 70's: LOW-RISE APARTMENT SURVEY

TABLE 24. TYPE OF HEATING SYSTEM

	*PERCENT OF RESPONDENTS** REGIONS				
	NORTH-EAST	NORTH CENTRAL	SOUTH	WEST	ALL REGIONS
Individual Warm Air Furnace	26	60	67	33	58
Central Boiler With Hot Water Baseboard	56	35	2	15	20
Electric Baseboard or Radiant Panels	17	10	5	45	11
Central Boiler With Air Handler in Each Apartment	0	3	15	0	8
Window Units or Similar Thru-The-Wall Units	7	6	5	0	5
Central Boiler With Fan Coils in Each Room	0	3	3	3	3
Heat Pump	0	1	4	3	3
Other	6	4	10	18	8

Of the seven types of heating systems reported in the survey, builders used two most of the time. However, usage varies widely by region. Over three-quarters of the builders used either individual warm air furnace (58 percent) or central boiler with hot water baseboard (20 percent). But national figures could be misleading. In the Northeast only 26 percent use individual warm air units, 56 percent use central boiler with hot water baseboard, and 17 percent use electric baseboard or radiant units. In the North Central region, there is considerably more than average use (35 percent) of the central boiler with hot water baseboard. In the South, the individual warm air units predominate, and more than average (15 percent) install a central boiler with air handles in each apartment. Electric baseboard or radiant panel heating is most prevalent (45 percent) in the West, while only one-third (33 percent) use individual warm air furnaces.

*PERCENTAGES do not necessarily equal 100 due to multiple answers.

TABLE 25. TYPE OF COOLING SYSTEM

	PERCENT OF RESPONDENTS*				
	REGIONS				
	NORTH-EAST	NORTH CENTRAL	SOUTH	WEST	ALL REGIONS
Individual Unit in Conjunction With Warm Air Furnace	24	57	71	18	58
Window Units or Similar Thru-The-Wall Units	76	47	9	64	31
Central Chiller With Air Handler in Each Apartment	0	4	14	0	8
Heat Pump	0	1	4	5	2
Central Chiller With Fan Coils in Each Room	0	2	3	5	2
Other	6	4	4	9	4

Most builders (58 percent) install an individual unit in conjunction with a warm air furnace. This is most popular in the South. Nearly one-third of all builders install window units or similar thru-the-wall units. These are especially popular in the Northeast and the West. The central chiller with air handler in each apartment is used to the greatest extent in the South and window or similar thru-the-wall units are least used in the South.

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* PERCENTAGES do not necessarily equal 100 due to multiple answers.

Apartment 70's: LOW-RISE APARTMENT SURVEY

TABLE 26. TYPE OF FUEL

	PERCENT OF RESPONDENTS*				
	REGIONS				
	NORTH-EAST	NORTH CENTRAL	SOUTH	WEST	ALL REGIONS
Heating:					
Gas	65	84	60	48	68
Electric	28	20	39	61	33
Oil	26	6	5	0	7
Cooling:					
Electric	100	92	90	95	92
Gas	0	8	10	5	8
Water Heater:					
Gas	56	50	63	58	59
Electric	26	43	33	42	35
Oil	22	7	4	0	6

Natural gas is the dominant fuel for space heating and water heating. Electricity is used by most builders for cooling. This holds true nearly everywhere in the country except in the West, where most builders install electric heat. More than an average amount of electricity is used for water heating in the North Central and Western regions. There is an above average use of gas for cooling in the South. The highest percentage of use of gas for heating occurs in the North Central region and the highest degree of use of gas for water heating is in the South.

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* PERCENTAGES do not necessarily equal 100 due to multiple answers.

TABLE 28. SOURCE OF HOT WATER

	PERCENT OF RESPONDENTS* REGIONS				
	NORTH-EAST	NORTH CENTRAL	SOUTH	WEST	ALL REGIONS
Individual Apartment Water Heater	35	44	47	48	45
Large Water Heater For Several Apartments	24	36	36	29	34
From Central Heating System Boiler	44	24	22	23	24

All builders use a variety of sources for hot water. Individual apartment water heaters are used by most (45 percent). Thirty-four percent use a large water heater serving several apartments and 24 percent provide hot water from a central heating system boiler.

The few regional differences are concentrated in the Northeast, where more than the average number of builders use hot water from a central heating system boiler and fewer use either an individual water heater in each apartment or a large water heater serving several apartments.

* PERCENTAGES do not necessarily equal 100 due to multiple answers.

Apartment 70's: LOW-RISE APARTMENT SURVEY

TABLE 31. TYPE OF TENANT

	*PERCENT OF RESPONDENTS** REGIONS				
	NORTH-EAST	NORTH CENTRAL	SOUTH	WEST	ALL REGIONS
Young Marrieds	63	74	63	70	67
Families	31	42	51	45	45
Elderly	43	31	19	21	26
Young Singles	17	27	17	18	21
Other	4	3	2	3	3

Nearly all respondents rent to a cross-section of tenants with young marrieds making up the largest group followed by older families with children. Both the young singles and elderly groups make up smaller segments of the rental market. This same pattern holds true generally throughout the country. However, there is an above average number of young marrieds and young singles in the North Central region, an above average number of family renters in the South and an above average number of elderly tenants in the Northeast.

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* PERCENTAGES do not necessarily equal 100 due to multiple answers.

PRIORITIZED LISTS OF ENERGY CONSERVATION ITEMS

This section contains lists of energy conservation items for each of three heating zones. Items were prioritized according to the Research Foundation's best estimate of each item's potential energy conservation values. In addition, a discussion of most of the energy conservation items is included.

Because rank-ordering of the lower value items was difficult and probably of little consequence, the lower ranked items could very easily be interchangeable on the lists.

For each zone, there are two prioritized lists -- a "Basic Package" list and a "Better Package" list. The Basic Package list might be considered those energy conservation items which would yield high energy conservation value at minimum cost. The Better Package list might be considered higher cost items which would considerably improve energy conservation of the dwelling but the cost might be prohibitive for general application.

General List of Energy Conserving Items

Building Envelope

- Insulate ceilings
- Insulate floors over unheated spaces
- Insulate walls
- Install storm windows
- Install storm doors
- Weatherstrip and caulk
- Add awnings or other shading devices
- Increase attic ventilation

Heating System

- Inspect and tune up furnace
- Install clock thermostat
- Add dampers in duct runs to unused rooms
- Install smaller capacity furnace
- Consider heat pump if electric heat
- Insulate ducts and tape joints

Water Heating

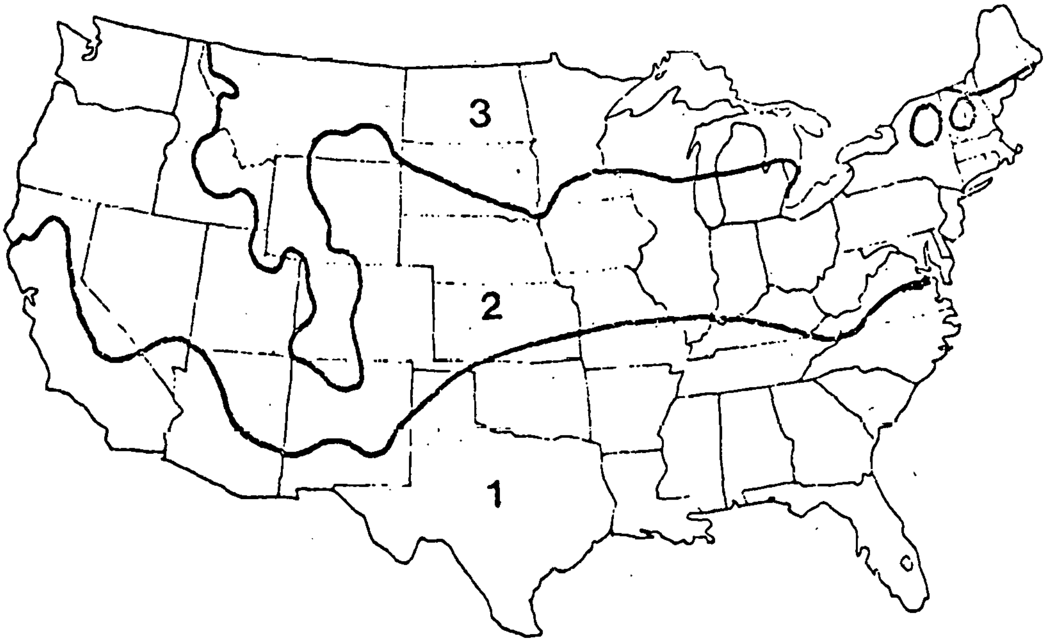
- Reduce temperature setting to 120°F.
- Install pipe insulation on exposed straight runs
- Replace washers on leaking hot water faucets
- Install low water use shower heads

Air Conditioning

- Inspect and tune up air conditioning equipment
- Install or replace with high EER unit
- Insulate supply ducts in unconditioned spaces

Custom Options

- Build in vestibule
- Enclose porch
- Add sun screens
- Modify roof overhang



1. Below 4,500°
2. 4,500 - 8,000°
3. Above 8,000°

Zones of Heating Demand

Prioritized List of Energy Conservation Items - Zone 1

Basic Package

Includes any or all items listed below, where applicable;

1. Add ceiling insulation to achieve total of about R-19
2. Weatherstrip exterior doors
3. Calibrate water heater temperature
4. Tune-up furnace/air conditioning system
5. Seal all openings and cracks in exterior walls
6. Weatherstrip and insulate attic access door
7. Install day/night clock thermostat
8. Inspect entire house for additional recommendations

Better Package

Includes items under Basic Package plus the following items, where applicable;

1. Add ceiling insulation to achieve total of about R-22
2. Tape joints and insulate ducts in unconditioned spaces
3. Install R-11 floor insulation over unconditioned spaces or add perimeter insulation with heated crawl space
4. Install storm windows, all living areas
5. Blow insulation in uninsulated exterior wall cavities (R-11)
6. Install ceiling fan for summer cooling
7. Add or increase attic ventilation

Prioritized List of Energy Conservation Items - Zone 2

Basic Package

Includes any or all items below, where applicable;

1. Add ceiling insulation to achieve total of about R-22
2. Install storm windows, all living areas
3. Install storm doors at all exterior doors
4. Seal all openings and cracks in exterior walls
5. Install day/night clock thermostat
6. Tune-up furnace/air conditioning
7. Calibrate water heater temperature
8. Weatherstrip and insulate attic access door
9. Inspect entire house for additional recommendations

Better Package

Includes items under Basic Package plus the following items, where applicable;

1. Add ceiling insulation to achieve total of about R-30
2. Install R-11 floor insulation over unconditioned spaces
3. Tape joints and insulate ducts in unconditioned spaces
4. Blow insulation in uninsulated exterior wall cavities (R-11)
5. Install 2x2 furring and R-7 insulation to basement walls
6. Install storm windows in basement area
7. Add or increase attic ventilation

Prioritized List of Energy Conservation Items - Zone 3

Basic Package

Includes any or all items below, where applicable;

1. Add ceiling insulation to achieve total of about R-30
2. Install storm windows, all living areas
3. Seal all openings and cracks in exterior walls
4. Install day/night clock thermostat
5. Install storm doors at all exterior doors
6. Weatherstrip exterior doors
7. Tune-up furnace/air conditioning
8. Calibrate water heater temperature
9. Weatherstrip and insulate attic access door
10. Inspect entire house for additional recommendations

Better Package

Includes items under Basic Package plus the following items, where applicable;

1. Add celing insulation to achieve total of about R-38
2. Install R-11 floor insulation over unconditioned spaces
3. Tape joints and insulate ducts in unconditioned spaces
4. Blow insulation in uninsulated exterior wall cavities (R-11)
5. Install 2x3 furring and R-11 insulation to basement walls
6. Install storm windows in basement area
7. Add or increase attic ventilation

The following optional items are in addition to the "Basic" or "Better" packages. They apply to any of the three zones, and are to be determined on an individual home owner basis where desired:

- Install awnings on East/West windows
- Replace incandescent lighting with fluorescent
- Install ceiling or window fans for summer cooling
- Replace shower heads with hot water saving type and repair defective faucets
- Build in vestibule at entrances
- Modify roof overhang for summer shading
- Add outdoor wind/sun screens
- Enclose porch
- Replace electric resistance heating with heat pump system
- Replace furnace with properly sized, efficient unit
- Replace air conditioning with properly sized, high EER unit
- Install attic exhaust fan

Insulation — It is apparent that the greatest factor in residential energy consumption is space heating (approximately two-thirds nationwide). Data on existing housing indicates that most homes are underinsulated, and many have no insulation at all.

Ceiling insulation in accessable attics can provide substantial energy savings by reducing heat loss and/or gain in the typical existing home in virtually any climate. Where there is no existing wall insulation, it is highly beneficial to blow in wall insulation in colder climates. Floor insulation over unconditioned spaces may also be justified, where accessable. Perimeter wall insulation may be substituted for floor insulation with crawl space foundations. Perimeter insulation may also be considered around concrete slab-on-grade floors in colder regions, although there is no universally practical method of providing this. Basement wall insulation should also be considered in colder climates where the basement is heated; this is particularly important where significant portions of the walls are above grade.

Insulation in general is probably the most obvious candidate for inclusion in any retrofit program. Some degree of insulation is considered beneficial in virtually any climate. The best type and amount of insulation is affected by many factors in determining the maximum benefit/cost ratio.

Storm Windows and Doors — Storm windows are probably the second most obvious candidate for a retrofit program, at least in regions having a heating season. They contribute significantly to energy savings by reducing heat loss through the very vulnerable glass area and, in addition, by substantially reducing infiltration of cold air around the typical window sash. Since most storm windows are actually combination windows, including insert screens, they can also contribute to summer comfort by encouraging natural ventilation. Basement storm windows should also be considered in colder climates where the basement is heated.

Storm doors perform the same function for exterior door openings, reducing heat loss through the primary door (especially doors with a large amount of glazing) and reducing infiltration around the primary door. However, since the total heat loss through exterior doors usually is relatively small compared to windows; cost/benefit considerations may relegate storm doors to colder climates.

Caulking, Sealing and Weatherstripping — A major factor contributing to heat loss in a typical home is infiltration of cold air through various cracks and openings in the exterior shell. Installation of storm windows and storm doors, as described above, will significantly reduce infiltration at door and window openings.

Weatherstripping of doors and windows will further reduce infiltration, but is not as significant where storm doors and windows are used. It is generally difficult to effectively weatherstrip existing windows, and little may be accomplished where storm windows are used. However, effective weatherstripping of exterior doors is possible and is recommended in any region having a significant heating season, especially where storm doors are not used. Special attention should be directed to the threshold area in weatherstripping doors. Weatherstripping of attic access doors should also be considered.

Other problem areas prone to infiltration include joints between foundation and floor, the floor and exterior wall, around window and door frames and at exterior corners of siding. Holes which penetrate the exterior shell — such as pipes, wires, exhaust fans, etc. — can also contribute to infiltration problems. It is sometimes possible to seal these joints with caulking, rope caulk, fiberglass strips or other materials, depending on accessability and other highly variable factors. However, the effectiveness of caulking and sealing is questionable except where there is an obvious problem and an equally obvious solution.

Heating/Cooling Systems — Most currently existing homes built prior to 1964 have either gas or oil-fired heating equipment (approximately 65 percent gas and 25 percent oil). More than one-half of these heating systems are of the forced air type, while perhaps 20 percent are steam or hot water. The balance includes a variety of floor, wall or room heaters, or no heating equipment as such.

Periodic maintenance and tune-up of central heating systems can provide as much as a 10 percent or greater increase in efficiency, depending on the present condition of equipment. A retrofit program should at least include an inspection of present equipment to determine general condition. Tune-up, where merited, would include such things as adjusting, cleaning or replacing burners and nozzles; cleaning the combustion chamber and flue (especially with oil-fired equipment); changing filters; adjusting dampers; calibrating controls; etc. A thorough inspection of the heating system would also serve to identify other problem areas such as leaky ductwork, uninsulated ducts in unconditioned spaces and equipment needing replacement.

Zone controls are available for most types of central heating systems. They make it possible to direct the heating or cooling to where it is needed, rather than conditioning the entire house all of the time. However, retrofitting existing homes with zone controls is a highly variable and usually costly operation, especially with a forced air system which is the most prevalent type. It is sometimes possible to accomplish a sort of zoning by simply installing dampers in a trunk or ducts serving little used rooms. While it is encouraged where feasible, zoning is not suitable for inclusion as a standard retrofit item.

Previous experience indicates that most home owners will not consider replacing heating equipment until necessary. In addition, industry sources verify that most newer equipment is no more efficient than older equipment, providing the older equipment is properly maintained. Therefore, there does not appear to be a great deal of potential in emphasizing replacement of existing functional equipment.

Where heating equipment is replaced for any reason, special attention should be exercised in properly sizing the new equipment. Past practice has often led to oversizing of equipment, resulting in inefficient operation. Bigger is not necessarily better. The properly retrofitted house will generally call for equipment of considerably lesser capacity than considered normal by the trade in the past. Properly sized equipment can result in a significant increase in operating efficiency.

Where a change in heating fuel or energy is considered in conjunction with equipment replacement, several factors should be weighed. Natural gas is generally regarded as the most efficient fuel, where available. Electric is generally regarded as the most costly, especially with the more common resistance heating equipment. This type of equipment should be discouraged.

Where electricity is the only energy source available, a heat pump should be considered. This type of equipment operates essentially as an air conditioner in reverse, and is capable of delivering more heat energy than the electric energy input. It is installed as part of a forced air system which provides cooling in summer as well as heating in winter. Heat pumps are especially well adapted to moderate climates, since their efficiency decreases somewhat as temperature drops. While operating costs are less than with electric resistance, it should be noted that heat pumps are considerably more costly to install and to maintain.

Air conditioning constitutes almost 17 percent of the energy load in a typical home in Zone 1, as previously designated; much higher in the warmer portions of Zone 1. The efficiency of air conditioning equipment varies substantially as indicated by an assigned Energy Efficiency Rating. Air conditioning equipment with a higher EER is available at additional cost, and should be used whenever air conditioning is installed or replaced. However, new installations of central air conditioning should not be encouraged in a program whose objective is to conserve energy. A more reasonable approach is to encourage installation of a ceiling or window fan in lieu of air conditioning in warmer climates.

One of the most promising energy conserving measures for the near term is to have home owners set back their thermostats during the heating season. It is generally agreed that a temperature of 65° - 68°F. is sufficiently comfortable during the waking hours. An additional set back of 5°F. or more during the sleeping hours will make a significant additional contribution to energy savings — 10 percent or more of annual heating energy. However, many home owners will likely neglect the nighttime set back due to forgetfulness or inconvenience, or because they dislike arising to a cold house in the morning. To encourage nighttime set backs, it is suggested that a "clock" thermostat be included as a standard retrofit item. These devices are widely available at reasonable cost.

Major Appliances — Major appliances commonly found in the home include refrigerator/freezer, range/oven, dishwasher, clothes washer and clothes dryer. As estimated previously, all together these appliances account for only 6.4 percent of the energy load in the typical home.

Although a new generation of "energy saving" appliances is beginning to emerge, they are currently restricted to the top line in cost and do not for the most part represent a significant contribution to conserving energy. The relatively high cost and the limited potential for saving energy all add up to the fact that appliances cannot be justified on a benefit/cost basis alone. Even if this were not so, replacement of working appliances would be difficult to justify.

Major appliances generally have a life expectancy of 10-plus years. Homeowners typically replace these one at a time as necessary through established retail channels. It is suggested that older less efficient appliances will be replaced through normal attrition by more efficient models as they become available. Inclusion of the above major appliances in an energy retrofit program does not appear warranted.

Water heaters are often considered to be an appliance. Water heaters are estimated to account for 13.6 percent of total residential energy load, more than twice that of all other major appliances together. The public generally has been oversold on the use of hot water, and most water heaters are set to deliver at least 150°F. water, either by the manufacturer or by the installer. The simple expedient of setting back the hot water temperature to 120° can significantly reduce energy consumption with little or no inconvenience to the typical household.

While it can be argued that any householder can set back his own hot water temperature, many heater controls provide no indication of temperature. Considering the negligible cost and the potential contribution to saving energy together with the known tendency of most people to procrastinate simple household chores, it is suggested that a retrofit package include calibration of existing water heaters to a working temperature of 120°F.

Calibration of the water heater will also provide an opportunity to inspect the condition of the present water heater. If the condition warrants, it should be replaced with a well-insulated unit of the minimum acceptable capacity. Where long runs of hot water piping pass through unconditioned spaces, it may be well to consider pipe insulation.

Other Current Technology — The literature search together with previous experience suggests consideration of certain additional measures for inclusion in an energy retrofit program. These items are more discretionary in nature and do not always lend themselves to calculation of definitive energy savings. While such items should receive a lower priority, it would be desirable to make them available where appropriate.

- Attic Ventilation — Many older homes do not meet modern attic ventilation standards. This poses a potential condensation hazard during the heating season and contributes to heat build up during the cooling season. The potential problem becomes greater when ceiling insulation is added. It is, therefore, suggested that existing attic ventilation be noted during the initial inspection and included in the retrofit recommendations where warranted.

- Awnings — Solar radiation through east, west and, to a certain extent, south-facing windows is a major contributor to heat gain in the cooling season. The addition of awnings or other shading devices will provide a significant reduction in cooling energy where central air conditioning is used, and should be encouraged in warmer climates.

- Lighting — Although lighting is not responsible for a significant proportion of energy consumption in the typical dwelling, there is some potential for conserving energy by replacing incandescent fixtures with the more efficient fluorescent type wherever appropriate. Installation of "task" lighting in specific locations will also reduce the energy required for general area lighting. Where continuously burning gas lights are used for exterior lighting, it is highly recommended that they be replaced with electric fixtures and electric-eye or hand operated switches. Gas lights consume an inordinate amount of energy.

- Plumbing Fixtures — Leaky or dripping hot water faucets can waste a surprising amount of the energy used to heat water. It is suggested that these be noted during initial inspection of a home and be included in the retrofit recommendations. Similarly, water saving shower heads or devices for insertion in shower heads are available for conserving hot water and may be considered as a retrofit option.

- Humidifier — The effective temperature, as perceived by occupants, may be increased by raising the humidity level of a home. This can permit a reduction in the thermostat setting of 3°F. or more, while maintaining equivalent comfort conditions. While peoples reaction to humidity conditions varies and the savings are not quantifiable, installation of a humidifier can contribute to energy savings.

- Crawl Space Moisture Control — All crawl spaces should be provided with a ground cover to prevent accumulation of destructive moisture. Where an effective ground cover is not present, careful installation of 6-mil polyethylene over the entire area is strongly recommended. If proper ventilation is not already present, this should also be provided. Where crawl space perimeter walls are insulated, operable vents should be used and the home owner should be instructed to close them during the heating season.

Custom Options — Several measures requiring modification to the home can contribute to energy savings. These measures generally involve structural or architectural modifications and are highly individualistic. Their cost may be substantial and it is not possible to generalize about energy savings. However, these measures can make a positive contribution to energy savings and might be considered as a retrofit option where appropriate. Several such possibilities are noted below:

- Build a vestibule into the existing home at the front entrance area where conditions permit. The inner door of the vestibule prevents an in-rush of outside air when the entrance door is opened, and is especially effective in cold, windy climates. A "mud room" may be built in at the side or rear entrance similarly.

- Enclose a porch or add an enclosed porch at the entrance to function as a vestibule. An enclosed porch can also form a buffer zone between the house and the outdoors, alleviating both winter heat loss and summer heat gain. Porch windows may be oriented toward the winter sun, while the roof may be designed for summer shading, with insect screens at window openings.

- Add sunshades, screens or trellis work to the house to shade windows, doors, patios or even a house wall. Direct or reflected solar radiation, especially through glazed areas, is a major factor in summer heat gain. Intercepting this radiation before it reaches the house wall or window areas is much more effective than internal sun devices such as drapes, shades or blinds.

- Modify roof overhangs to shade windows, doors or the house walls from the summer sun. Properly designed, the overhang will admit the winter sun, which is at a lower angle. Roof overhang extensions need not be solid or continuous, but may be constructed of durable lumber or other materials to form a trellis effect.

- Alter windows or remove them to reduce glass area and associated heat loss or gain. Replace existing window units with higher quality units to reduce infiltration; use double insulating glass in colder climates to reduce heat loss. Reorient windows to avoid east and west exposures in warmer climates where conditions permit.

- Alter doors or replace them where warranted to reduce infiltration or other sources of heat loss or gain. Avoid doors with a large amount of glazing or sidelights, and avoid double entry doors which are difficult to weatherstrip effectively. Consider installation of an automatic door closer. Sliding glass doors are notoriously poor from a standpoint of heat loss or heat gain and infiltration, and may sometimes be replaced with a more functional hinged door or even a window.

"Newer" Technology — The literature search for additional retrofit candidates produced a number of items representing "newer" technology. These items generally were found to be unacceptable for inclusion in a standard retrofit package at the present time due to a variety of limitations. Most preclude a favorable benefit/cost ratio in the near term. Some, however, show promise for future consideration as the state of the art evolves and as availability, pricing, reliability and other questions are resolved.

- Stack heat recovery is possible with a device which is based on the heat pipe principle. The device installs on the flue pipe of gas or oil-fired equipment and directs recovered heat into the surrounding air. Cost, availability and code restrictions presently limit use, and in-use performance experience is limited.
- Automatic stack dampers which close off the flue of gas or oil-fired equipment when it is not running can reduce heat lost to flue draft. It is reported that these devices are being incorporated into some new high efficiency equipment, but those models designed for retrofit pose a potential safety hazard until proven.
- Open air cycle may be built into a forced air cooling system to circulate outside air throughout the residence in lieu of air conditioning when outdoor conditions permit (such as evening hours).

Sophicated controls are required to activate dampers when outside wet bulb temperature is lower than that of the return air. The cost of controls and necessary duct work is considered excessive for a retrofit program.

- Electric igniters on gas-fired equipment could save a substantial amount of gas now used by continuously burning pilot lights. These devices are being fitted to some new appliances and equipment, however, a universal model suitable for retrofit is not generally available as yet.
- Heat exchangers installed on heat producing equipment, such as refrigerators and air conditioners, could be utilized to heat or preheat water for domestic use. Such devices suitable for retrofit are not currently available. To be practical they must be built into the original equipment and, even then, the additional cost of installing the equipment could be substantial.
- Appliance venting to the outdoors during summer would remove unwanted heat from the interior. In winter, exhaust heat could be redirected to the interior to contribute to heating. This concept might apply to range/ovens, dishwashers, refrigerator/freezers and clothes dryers. It shows special promise with clothes dryers, since they are normally vented to the outside and could be redirected to the inside in winter with little modification. However, the necessary devices and techniques are not currently available.

- Ductless bathroom fans which provide for odor control are now available. These fans avoid exhausting conditioned air to the outside, as well as loss through ill-functioning dampers of conventional exhaust fans. However, the ductless fans are not yet widely accepted due to "health" considerations. Also, the potential energy savings does not appear commensurate with replacement cost.

- Solar water heating systems show considerable promise as an an energy saving option in the future. The substantial cost of installation and the current state of the art, however, rule this out as a viable retrofit possibility for several years.

- Solar space heating systems, similar to water heating systems, show great promise for the future. However, standard hardware components and definitive design data are not presently available. In addition, the substantial projected cost of the necessary collector, storage, heat exchange and control components make it unlikely that solar space heating could ever be considered as a standard retrofit item.

- Solar space cooling is possible using solar energy to operate special cooling equipment. However, the present state of the art is such that solar cooling will not be a practical reality for a number of years. It will certainly be preceeded by solar heating and will certainly cost substantially more than solar heating. Solar cooling is not a candidate for a national retrofit program.

- Roof spray or trickling with water can reduce heat gain through the roof or ceiling in warm regions. Heat recovered from the circulating water can also be used to heat or preheat domestic water. However, the considerable expense of such a system together with the limited energy savings potential rule this technique out for residential retrofit.

- Mechanical attic ventilation can contribute to cooling energy savings in warm climates by lowering attic temperatures. Thermostat controlled power ventilators are now widely available. The older style wind actuated turbine is also helpful. However, these devices are effectively limited to very warm climates for a favorable benefit-to-cost. Even then, operating cost may outweigh savings if ceilings are heavily insulated (R-22 or more).

- Heat absorbing glass (tinted glass) or reflective glass can substantially reduce heat gain in warmer climates by reducing solar radiation through east and west and, to a lesser degree, south-facing windows. However, the cost of replacement or addition with the special glass is considered prohibitive for the retrofit program contemplated. A more practical solution is to employ shading techniques such as awnings, shutters, trellis or plantings.

- Sun control film for application over existing windows is now widely available at reasonable cost. While life expectancy is not known and experience is limited, it appears to be a low-cost substitute for reflective glass and has some potential for retrofit in warmer sunny regions.

APPENDIX I

MIXED STRATEGIES FOR ENERGY CONSERVATION AND ALTERNATIVE ENERGY UTILIZATION IN BUILDINGS

Contract Number ERDA -- E(04-3)-1234

May 1, 1977

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ENERGY CONSERVATION BY ARCHITECTURAL AND ENVIRONMENTAL DESIGN

As the President of the United States has recently enunciated, energy conservation is the most immediate and effective way that the impending crises in diminishing energy resources can be met. Conservation in the areas of transportation and building design and utilization alone would have an impact on about 60% of all of our energy consumption. Of this, about 34% is used in buildings.

On the conservation side of a mixed strategy for energy conservation and utilization in buildings, there are two primary considerations:

- Conservation by technical performance of materials and systems
- Conservation by environmental design

The major thrust of this study focuses on the improvement of technical performance in building construction. This Appendix will discuss strategies in environmental and architectural design that can effectively reduce energy demand.

1 SITING AND ORIENTATION

a. WIND CONTROL

In computing the Δt for determining the desired U factor in designing the envelope walls of a building, the computations are sometimes developed on the basis of still air and sometimes on the basis of an average wind velocity in the region in which the building is situated. When average wind velocity is factored into the computation, it is applied to the windward surfaces in the direction of the prevailing winds, as a direct effect. Part of this effect is the heat loss through the building envelope by cooling of the exterior surface. The other part, and the more significant factor, is the infiltration of cold air through the normal cracks around openings and at joints in most conventional building envelope assemblies.

In those cases where average wind velocity has been factored into the heat transfer calculations, it has been used for determining the desired U factor in designing a particular wall. Little if any attention has been given to design strategies for controlling wind effects external to the building surfaces. That these effects may be significant conductive heat transfer and infiltration loss consideration is demonstrated by the following table:

WIND CHILL FACTOR

Wind Velocity in M.P.H.

Ambient Temp.	5	10	15	20	25	30	35	40	45
60	60	59.5	59.0	58.5	58.0	57.5	57.0	56.5	56.0
40	40	38.3	36.7	35.1	33.6	32.0	30.5	28.9	27.4
20	20	17.3	14.8	12.3	9.9	7.4	5.0	2.5	0.1
0	0	-3.5	-6.8	-10.1	-13.3	-16.6	-19.8	-23.0	-26.2
-20	-20	-24.2	-28.2	-32.2	-36.1	-40.0	-43.9	-47.7	-51.6
-40	-40	-44.9	-49.5	-54.0	-58.5	-63.0	-67.4	-71.9	-76.4

Heat loss effects through the building envelope by wind is not always undesirable. In some regions, during the cooling season, if the prevailing wind is from the north and east or from the opposite direction of the sun during various times of day, increasing the heat transfer through the building wall may have a beneficial affect in reducing the load on mechanical cooling equipment. The architectural implications of this consideration may lead to the design of exterior walls with a variable U factor capability. By altering the surface treatment of the wall on a seasonal basis, its capability to transfer heat by conduction can be varied to respond to demand. However, for heat transfer by through-wall conduction to be of more than the most marginal significance, sufficient air flow must be present.

A more important consideration is the control of heat loss/gain caused by infiltration through joints in the building assembly. Some of this can be effected by a tighter, more carefully sealed, construction. To accomplish this to a meaingful extent--particularly in single-family residential construction, but also in commercial and institutional buildings--would require substantial changes in prevailing construction standards, codes and techniques. A more immediate way to exercise control--assuming that relative wind velocity is a significant factor--is the employment of environmental and architectural design components to intercept and redirect the wind before it strikes the building surfaces themselves. In this consideration variable control may also be a factor, including the following:

- Deflection or decreasing direct wind impacts during the heating season by interception.
- Variable control of wind impacts of the building surface in response to seasonal heat transfer demands.
- Control of wind velocity.

The strategies available for wind control external to the building surface, rely on the use of three primary environmental design elements:

- Plant Material and Trees
- Topographical Features/Earth Berms
- Built Elements/Walls

PLANT MATERIALS AND TREES

Plant materials and trees, particularly deciduous varieties, have as a natural characteristic, the capability for variable wind control. Unfortunately, in the temperate zone which constitutes most of the Continental United States, deciduous growth is most dense during the summer, when increased wind velocity may be desirable for cooling effects and least dense during the winter when maximum blockage of direct wind impacts on building walls is likely to be most beneficial.

The most likely typical case in wind control is one in which it is desirable to block or deflect winter winds from striking wall surfaces. In these instances, the blockage can be achieved by placing plant material in the prevailing wind path. The amount of effect is a direct product of the density of the plant material (Fig. 1).

The alternative case is one in which it is desirable to increase the wind velocity along building surfaces for cooling. This can be accomplished by developing "wind tunnel" affects by placing plant material parallel to building surfaces. In this application, the variable characteristics of deciduous material may be significant. During the cooling season (summer) when increased wind velocity is desirable, the plant material is most dense, increasing the "wind tunnel" effect. During the heating season (winter) the same plant material, without leaves, looses it density and becomes "pourous", reducing its capacity to increase the velocity of wind currents passing between the planting and the building surface (Fig. 2, Fig. 3).

TOPOGRAPHICAL SHELTER

Like plant material, the use of the natural topography in the placing of buildings, or the creation of banked earth shelter can be used to control wind effects. Building on the leeward side of natural topographical wind breaks was a common pre-industrial technique. With an improved understanding of aerodynamics this technique is not only still viable, but can be made sophisticated tool in the control wind impacts (Fig. 4). The factors of influence are:

- The section profile of the topography.
- The scale of the shelter enclosure in relation to the topographical profile.
- The direction and velocity of prevailing winds.

At the design level of individual buildings, the opportunity to take advantage of natural topography may be too infrequent to make it a standard element in energy conservation design.

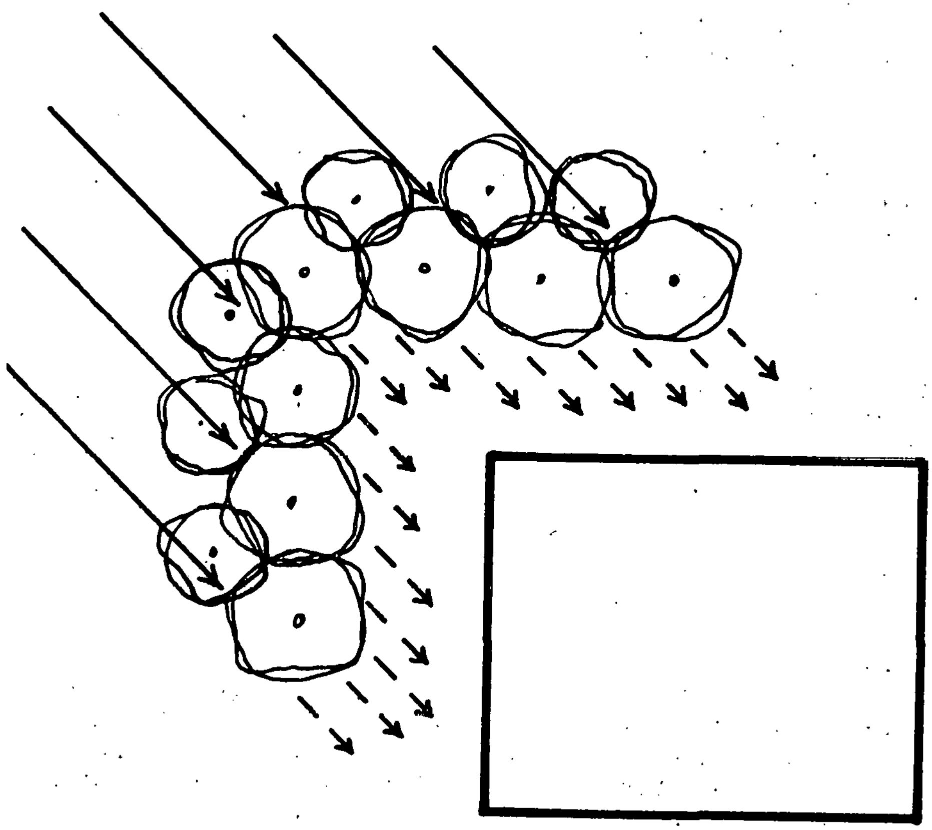
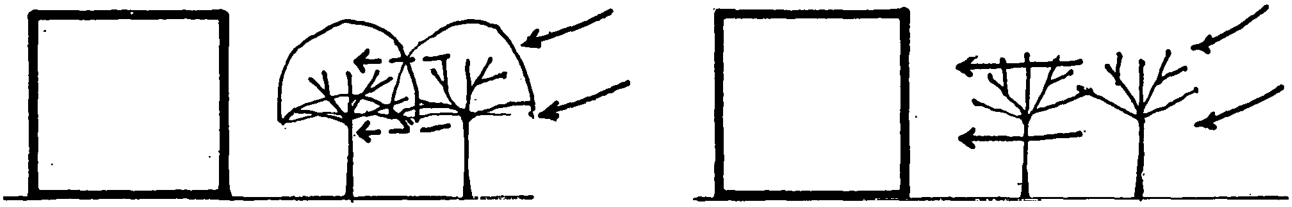
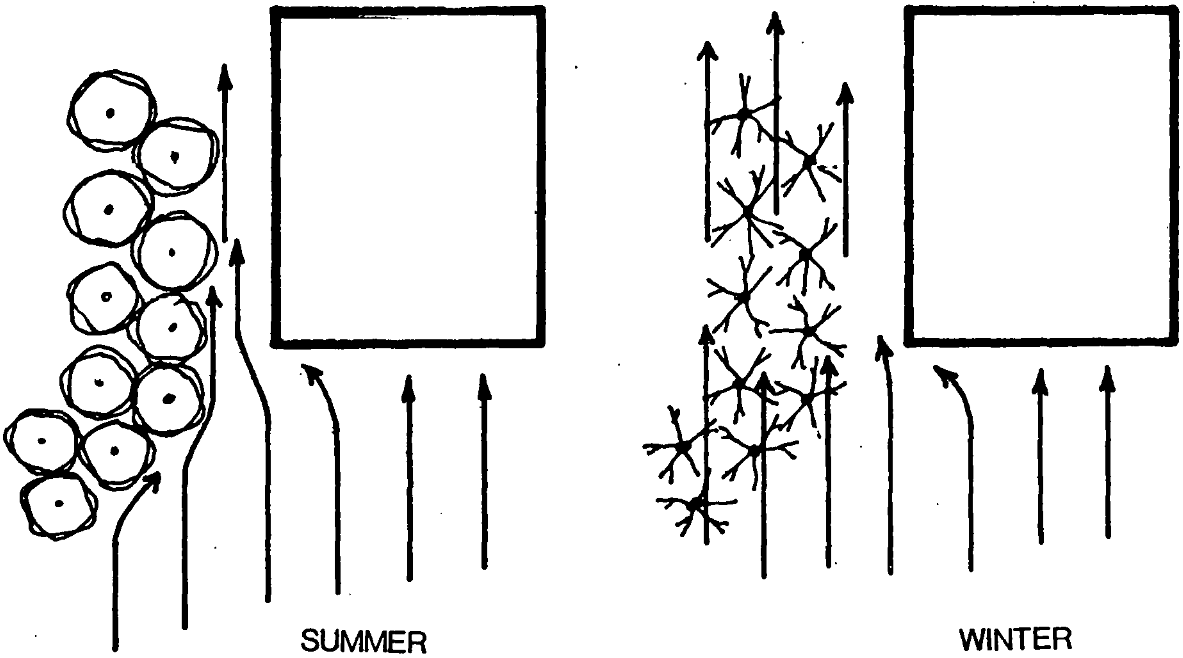


FIGURE 1



SUMMER WINTER

FIGURE 2



SUMMER WINTER

FIGURE 3

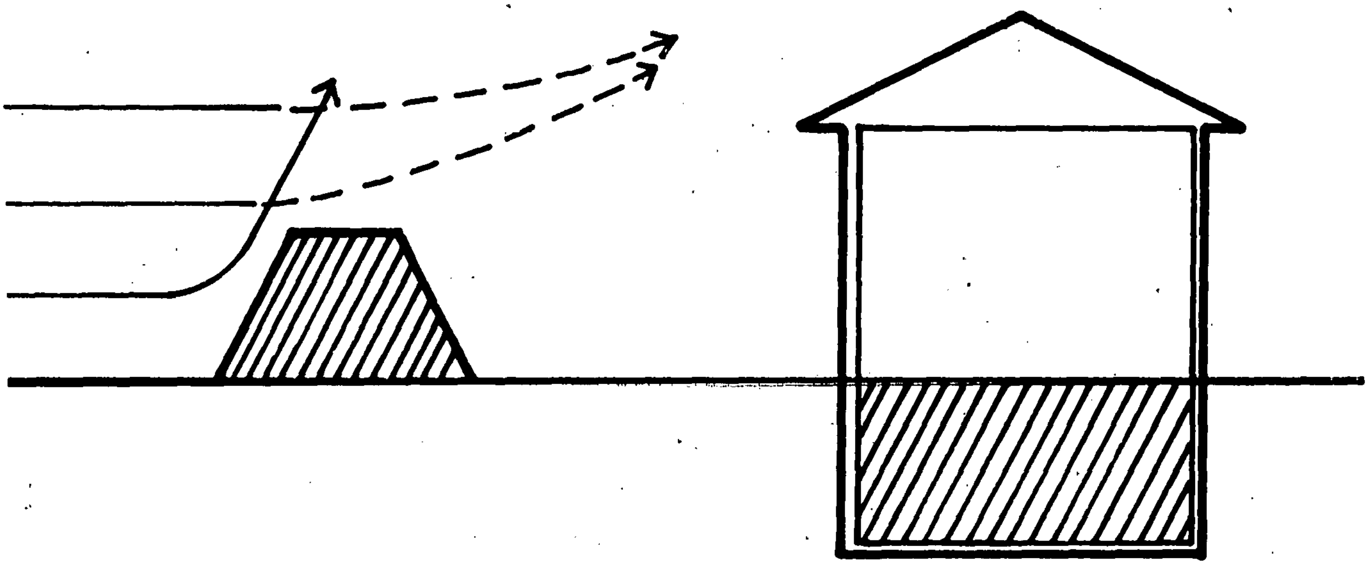


FIGURE 4

However, mechanically re-shaping the surface of a building site to create artificial wind control is not only a routinely available opportunity, but may prove a more cost-effective technique for controlling heat transfer than adding insulation to the building envelope. For instance, taking the excavated fill from an 1,800 sq.ft. two-story house a banked earth "wall" 6 ft. high, 18 ft. at its base and with a 6 ft. flat top could be created on two sides of a 50 ft. by 100 ft. lot. Such a wall, placed across the path of the prevailing wind, would have a spoiling effect, reducing the wind chill factor on its other side. With the addition of plant material on top of it, the effect would be even more dramatic.

Topographical shelters have an advantage over trees and plant materials in that they are both more dense and more permanent. However, earth mounds, or berms, cannot be expected to exceed a maximum height-to-width ratio of 1 to 2, which limits their efficiency in the use of site area. On sites of adequate size and in relation to low rise structures, they can do an effective job of controlling the cooling effects of the wind.

BUILT SHELTER/WALLS

Of all of the techniques conventionally available for sheltering building envelopes from the wind, walls are the most mallable. They may be more finely and reliably adjusted for density and directional control than plant material and are more space-efficient and flexible than earth berms. However, their cost-effectiveness, relative to alternative construction strategies (such as adding more insulation to the building envelope itself to overcome the increased heat transfer of the unprotected walls) is somewhat dependent of the unique conditions of location, setting and other needs. Under the best conditions, wind control walls on the site may also be serving other purposes, such as providing privacy screening or security (Fig. 5).

The selection of a strategy for controlling wind effects is dependent upon the unique conditions pertaining to each particular site. The use of plant materials, earth berms, walls or any combination of them may be significant factors in energy conservation design only if they can be applied as a reliable and predictable component in controlling heat transfer effects caused by prevailing winds. This in turn requires an analytical process for determining the aerodynamic changes caused by each particular design in each particular case and application of the results to the Wind Chill Factor Chart.

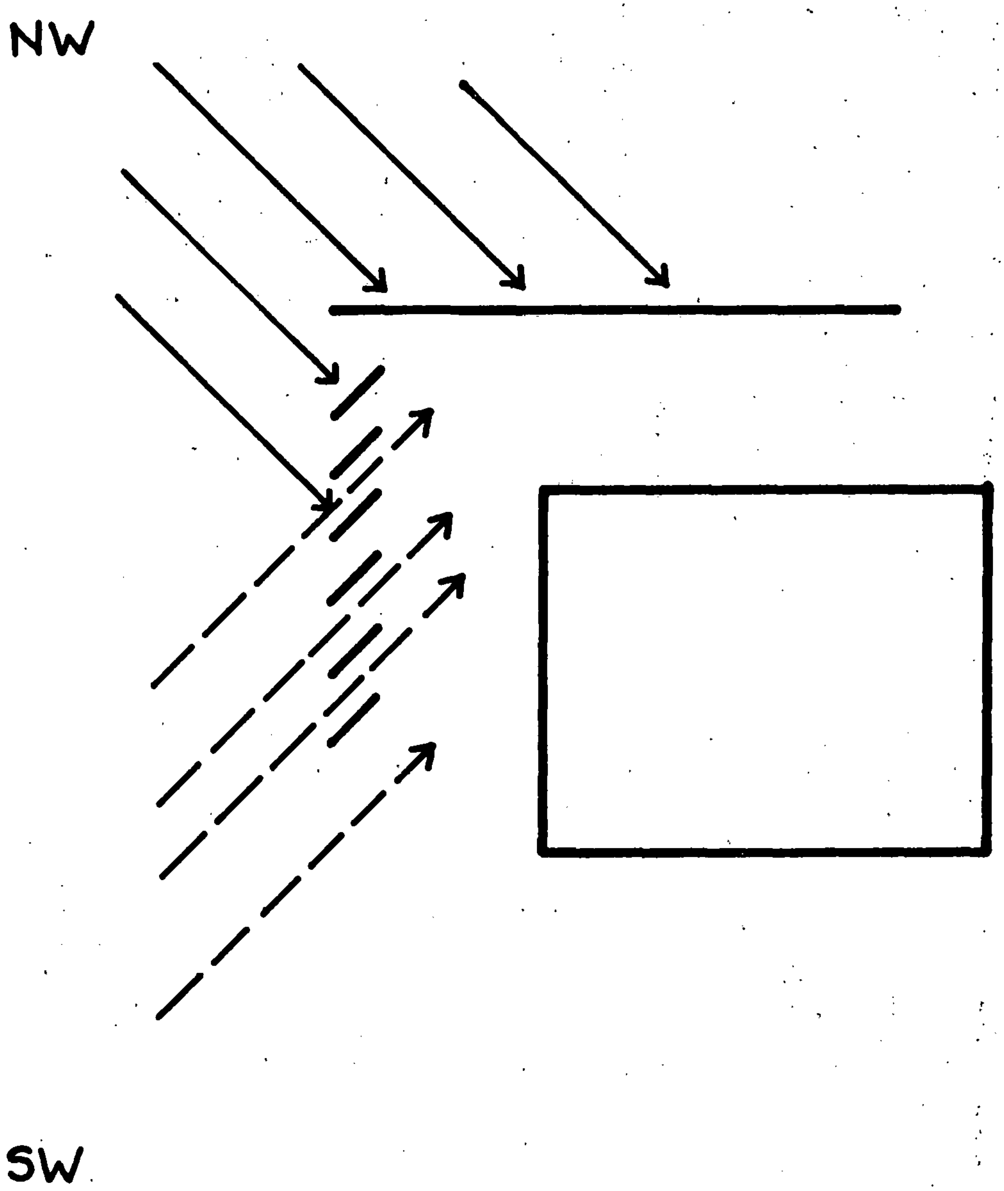


FIGURE 5

The factors in this analysis are as follows:

A. Wind Velocity Decrease (cross-wind barriers)

B. Wind Velocity Increase (wind-tunnel effects)

C. Wind pattern changes between the lee side of the wind barrier and the building envelope

A. Wind Velocity Decrease

Velocity decrease and its effect on infiltration and thermal conduction may be taken as a function of the density of the wind barrier and a vector analysis of the velocity of the prevailing winds, as illustrated in Fig. 5.

B. Wind Velocity Increase

Velocity increase calculations require an aerodynamic analysis which accounts for the velocity and direction of prevailing winds and the geometry of the "wind tunnel" formed between the building envelope and the wind control element. (Fig. 3)

C. Wind Pattern Changes

The extent to which the wind barrier alters the micro-climate immediately around buildings by changing the pattern of air movement requires case-by case aerodynamic analysis. The conditions under which such analysis may be particularly useful in respect to reducing infiltration loss as it applies to reduction by thermal conduction, it is probably limited to more complex, multi-building, large scale developments where the incremental affects of relatively small individual impacts may have a cumulative affect on the overall development.

b. HEAT SINKS/COURTYARDS

Just as external wind barriers may have a beneficial effect on wind chill impacts, the building itself may be used as a barrier to shelter its own exterior exposures. This may be accomplished by creating atriums or interior courtyards. The energy conservation advantage of this technique, particularly in cool climates, is that creates a still air pocket, which will trap the warmth from the sun, into which the majority of the required light and ventilation openings may be faced, while the exterior envelope may be kept relatively solid (Fig. 6).

Strangely, the atrium building is historically a warm climate development, where its origin was apparently primarily influenced by concerns for security, not climate control. In fact, most pre-industrial Mediterranean atrium buildings had courtyards surrounded by open collenades, to allow the residents an exterior space protected from the sun. Northern European buildings never developed the interior courtyard as a climate control device either. Instead, the primary response was small openings and dark interiors.

In contemporary buildings, the energy conservation impact of atrium design may be measured by comparing this building organization, with the majority of openings facing into the still-air/trapped-heat pocket against a building, equal in all other respects, in which the same amount of opening and fenestration is distributed along the exterior walls. Such a calculation would also have to account for the greater amount of exterior wall area required for the atrium scheme. The equation for this comparison includes a measure of:

- Total Wall Surface
- Wall Surfaces @ Prevailing Wind Chill Conditions
- Fenestration @ Wind Chill Exposures
- Crack Areas Exposed to Windward vs Still-Air Exposures

c. PORTAL ORIENTATION

One significant factor in heat loss, particularly in commercial, school and merchandising buildings, where large numbers of people enter and exit over extended time periods, is the orientation of entry portals in respect to prevailing wind direction. Under conventional conditions, little attention

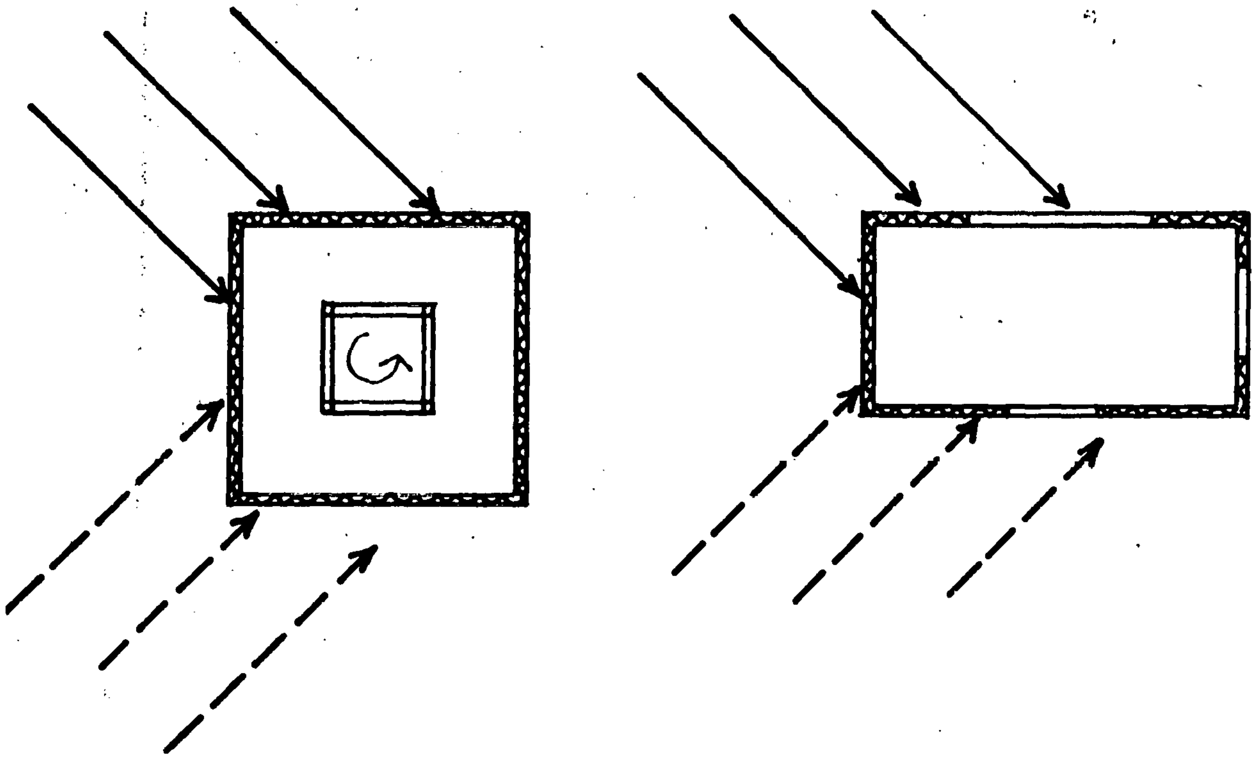


FIGURE 6

is given to wind effects at points of entry. In most contemporary buildings in northern climates a double-entry is used. This is normally heated at high volume (air) or high temperature (gravity) to compensate for heat loss at the entry.

The effect of orienting the primary portals, or points of entry, so that they are sheltered from the direct impact of the prevailing winds to reduce the heating load in the vestibules may affect the total demand to a significant extent in buildings with multiple, frequently used entries.

In all of the energy conservation considerations which apply to this sub-section, the concept of wind chill is the central concern. Application of wind chill factors to the various design alternatives is the primary measure for the performance characteristics of each design and the effect on energy demand in respect to the cost of implementing it is the ultimate test of cost-effectiveness.

2 GEOMETRY AND ACTIVITY ORGANIZATION

The geometry of a building and the activity within are important factors in the conservation of energy in structures. Though each of these factors influences building design in a different way, they are inter-related and often have a substantial effect on both initial and life-cycle costs in building construction and operation.

Comparing pure geometries, disregarding factors of use and construction constraints, the most energy efficient geometric configuration for a space is a sphere. However, this is an impractical form for most human activities and must be relegated to a largely theoretical consideration. Some exceptions in man-made habitable structures which approximate this shape are domes and igloos). Simplifying this form somewhat to a space which describes a circular floor and a cycindrical volume results in a less energy conservative but nevertheless still efficient plan. This is basic floor plan geometry, a circle, encloses the most area with the least perimeter. A space of this shape requires 22% less wall surface to enclose the floor area than would be required for a rectangular plan enclosing the same amount of area.[1]

A cube is the closest volumetric approximation to a sphere and lends itself more readily to practical application. A square floor area is also economical, being 12% to 15% more efficient in perimeter than a rectangular floor area.[2] As it is a more likely form to build with existing technologies and materials, the cube is the practical volumetric baseline against which other geometric configurations can be measured for energy savings. Given this condition, one measure of the potential energy efficiency of a structure may be considered a function of its digression from a cubical geometry (Fig. 7).

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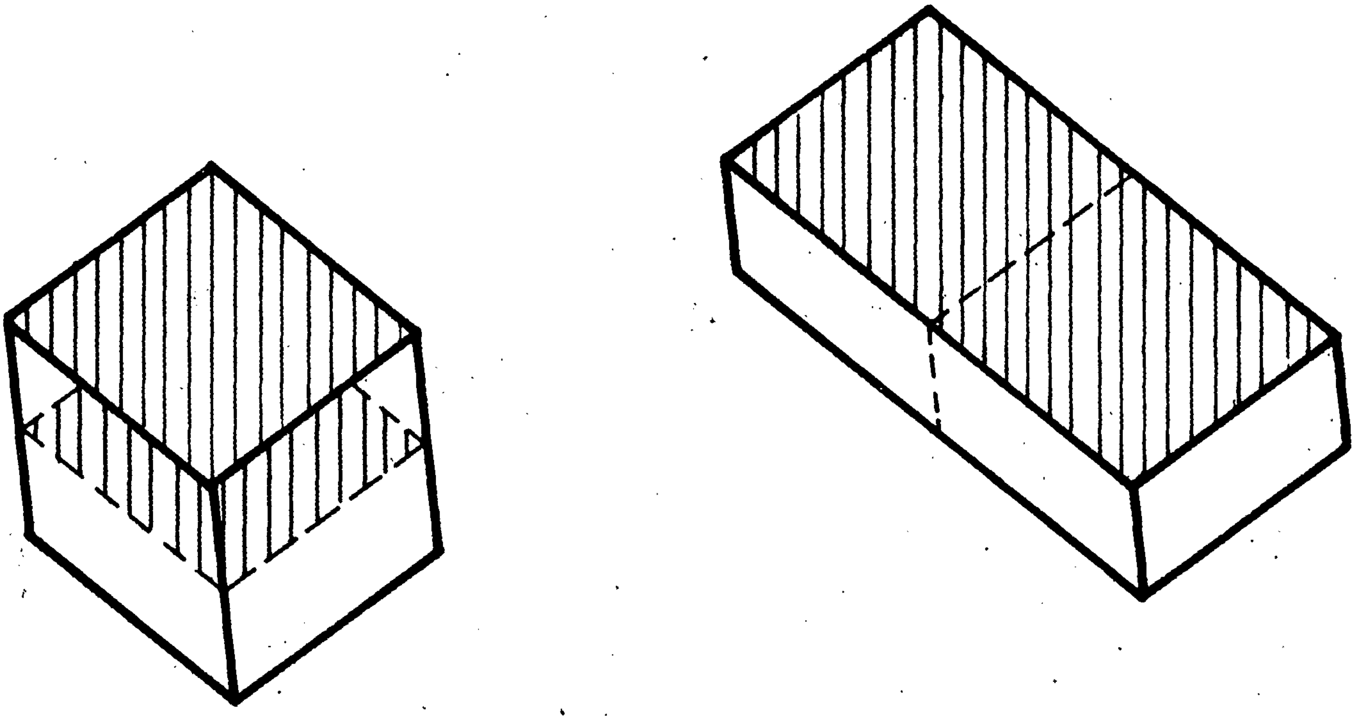
[1] Fitch, James Marston. American Building: The Historical Forces That Shaped It, (Houghton Mifflin Company Boston, The Riverside Press Cambridge, 1966).

[2] Ibid.



LESS EXPOSURE

MORE EXPOSURE

FIGURE 7

The application of this measure is useful only under those conditions where the deliberate design of other geometries to use prevailing climatic conditions as a part of the environmental control system are not applicable. A particular instance of the might be additions and remodelings to existing buildings in which the prevailing conditions of orientation, fenestration, exterior skin design and energy systems are pre-established.

Just as the geometry of a building can effect energy savings through the shape of the enclosing "skin", it is also related to the activity within and through this, the conservation of energy. It is this relationship of building geometry to internal activity which defines a building type. This interrelatedness is often a result of regional conditions, in terms of climatic forces, economic necessity, or regional industries and activities. What has become apparent is that the building type as a routine point of departure for design shapes a structure more than any other consideration. With the increasing sophistication and interrelatedness of the industrial infrastructure after World War I, the consideration of regional conditions in building design were set aside in favor of uniform construction processes and components. Distortions in the performance of particular building types in responding to local climatic conditions were overcome by increasing utilization of more and more elaborate mechanical systems. This process can easily be demonstrated by looking at it in an historical context and comparing regional design differences.

If we briefly review the history of American building prior to the first World War as an example of design evolution, we see a fairly representative picture of the natural process by which buildings have been shaped through time by the conditions of the natural environment. The range of distinctive, unique geographical areas and climatic conditions in the U.S. is such that any building modifications due to these factors has been greatly magnified. The country can be said to have four major areas of regional influence on building design: The East coast and Midwest, the South, the Southwest, and the Delta region of the Mississippi River.

New England settlers naturally built structures that were direct copies of their European counterparts. "This resulted in an architecture that utilized building concepts and techniques that were developed in climates and terrains quite different and not especially suited for conditions occurring here."[3] The Northern houses eventually took on a geometric shape that was compact and centralized; cubic in form with small windows, small rooms and low ceilings. They were made of the available materials at hand; usually wood, sometimes masonry.

The South saw the development of the plantation style home. With the hot weather conditions prevalent along the Eastern Seaboard it was common for structures to have high ceilings, large windows and wide porches and porticos all serving to encourage natural air circulation. These details became progressively more pronounced the further South one went.

The Mississippi Delta produced the logical extension of these principles with stilted, airy buildings surrounded on the periphery by galleries and deep shading balconies. Ventilation was realized by floor to ceiling windows, high ceilings, and large central halls.

In the Southwest, climatic conditions were such that homes became introverted, with central convered patios and thick walled mud-masonry. Windows on the exterior were limited in number and much smaller, while openings onto the patio were larger. The thick walls produced the required "thermal lag" in keeping inside temperatures at a comfortable median between the extreme daylight highs and the night time lows.

As a response to industrial exigencies, these "evolved" design characteristics, underwent great changes in rapid sequence after each World War. No longer was there a need to limit the form of a building to a specific region. A family in Minnesota could have an "authentic" hacienda from the Southwest regardless of how much energy was needed to keep it warm in the winter. The long, low roofed ranch-style house of California, made popular by the press, soon became the Standard American House and was placed in whatever locale desired. Instead of working with the climate, as did pre-industrial development builders the contemporary builder must pump in as much oil, electricity and natural gas as is needed to heat the building in the winter and cool it in the summer.

This suggests that a real issue in designing for energy conservation in buildings is the need for a return to an awareness of regional climatic conditions as a factor in the design process.

a. SINGLE FAMILY HOUSING DESIGN

As was demonstrated in the previous section on regional differences, the most efficient shape a house can take will be a cubic one, or one closely resembling it. This does not mean that life styles should be changed to fit the space of a building. Rather it is suggested that builders return to an understanding of natural forces and the corresponding housing forms on a regional basis. It is still possible, within the recommended guidelines and with attention to energy conservation details, to build housing with the variety of styles available today. The activity within a residence will not change greatly over the years in any event. Activity organization in homes has always been dictated by convention; i.e., the bedrooms are grouped together, the kitchen and dining spaces placed in close proximity to each other, living and play spaces separated from work spaces, and so on.

MULTI-FAMILY HOUSING DESIGN

A multi-family dwelling will yield energy savings similar to those of a single-family residence, designed as described in the previous section, if the overall building form is close to a cube in geometric form, the individual units within the structure are much deeper than they are wide, and the building is limited to three or four stories in height. The reasons for this are:

1. A cube is the best energy conserving geometric form aside from a sphere.
2. Units which are long and narrow expose only the shortest wall to the exterior and provide less heat loss.
3. A three to four story walk-up building eliminates the need for energy consuming elevators.
4. High rise buildings have a high thermal loss due to wind chill factors.

COMMERCIAL/INDUSTRIAL

Traditional patterns of industry and commerce are such that a wide variety of forms have been acceptable.

There is no reason that an industrial or commercial facility cannot change its geometric configuration to a more energy efficient one, provided the change does not violate the functional activity of the business. A building design for an industrial complex will be more effected by the manufacturing process than the need to heat, ventilate or air condition the spaces within. Therefore the design will reflect the conditions of activity, process and movement and must be analyzed on this account for the greatest energy conservation measures. However, many industrial processes create excessive heat as a normal consequence of their operation and can be "tapped" for this excess to heat adjacent spaces such as offices and control rooms.

The opposite might be true in some instances; the industrial process might involve large amounts of cooling and would thereby afford possibilities of air-conditioning for nearby office spaces. Nevertheless, architects will have to be conscious of regional considerations as the placement of these smaller "climate controlled" spaces (offices control rooms, etc.) can be affected by local climatic conditions. For small industrial settings in cold climates this means that the work spaces and the office spaces can share the same building envelope; the offices benefiting from the surplus heat from the work spaces. In warm or hot climates the sensible condition would be to have work space and office space independent and possibly in separate structures. Reverse these conditions if the industrial process is a cooling excessive rather than heat excessive one (Fig. 8).

EDUCATIONAL/INSTITUTIONAL

Educational facilities have spaces which can be divided into two types: general use spaces and special use spaces. Each of these two categories has two sub-groups: high occupancy spaces and low occupancy spaces. Depending on the particular combination of high or low occupancy and general use or special use, a space can be modified to achieve energy conservation.

For example, General Use spaces tend to be smaller and more flexible than special use spaces. Geometric considerations indicate that rooms of this nature will follow the principle of the multi-family dwelling unit and take on an elongated shape, thus reducing the exposed perimeter wall area and decrease heat loss. If a general use space has low occupancy it should be placed on the perimeter of the total building. A general principle is that perimeter spaces act as a buffer between the exterior conditions and interior spaces.

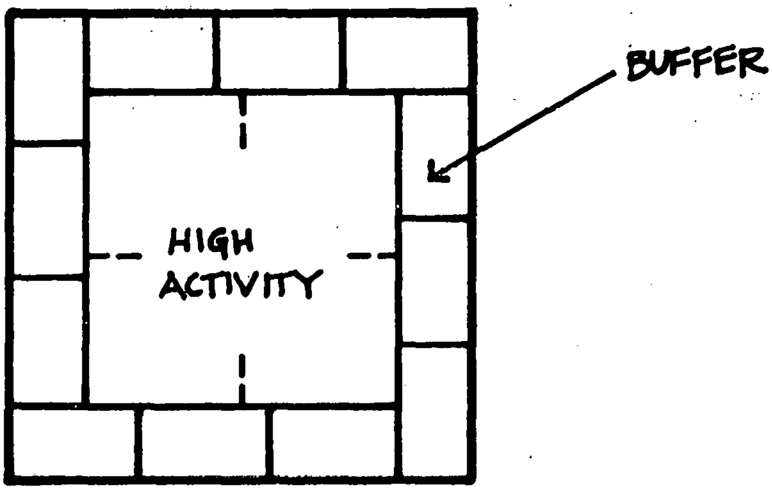


FIGURE 8

3 SUN CONTROL

Control of solar impact is among the most significant issues in designing buildings for energy conservation. Solar impact operates directly on buildings in several ways.

- MICROCLIMATE

  By affecting the immediate atmospheric environment it establishes the general medium of temperature and humidity around the building envelope. This influences the characteristics of infiltration effects and also creates a diffuse condition which causes changes in the properties of building materials.

- RADIANT PENETRATION

  Because most buildings have glazed openings, direct sun radiation through glass into building interiors affects the heat gain/heat loss demands placed on the comfort control systems. Radiant penetration through non-glazed portions of the envelope assembly (which constitute the majroity of the exterior surface) also affects energy demand.

- CONDUCTION/CONVECTION

  As a secondary effect, solar penetration through glazed opening and the radiant heating of building surfaces affects the convection of air in building interiors.

This Section will discuss the architectural/environmental design considerations which must be addressed in order to develop energy conservation strategies which will reduce the energy demand required to maintain acceptable comfort levels in interior spaces. The particular issues which will be discussed are as follows:

a) Fenestration

b) Sun Shading on Windows and Walls

c) Envelope Surfaces

d) Thermal Mass

a) FENESTRATION

Direct radiant heat transfer accounts for the majority of solar gain in buildings. Although the primary attention of this discussion will focus on heat gain in building interiors due to solar radiation, heat loss by radiation outward from the building interior is also a significant factor which should influence design.

The primary component in the building envelope through which radiant heat transfer occurs is the window openings. Despite great technological improvement in its design, the U factors of glass, it cannot compare on a cost-effectiveness basis with any number of common solid wall and roof assemblies. Recognition of this must lead to the conclusion that a careful consideration of the amount, location and orientation of glazed window openings in the building envelope as an architectural consideration may have a more significant affect on total radiant heat transfer than the design of the glass itself.

With the availability of "cheap" energy and development of elaborate mechanical systems for buildings which has prevailed in the U.S. since the end of World War II, a building style, particularly for commercial and institutional buildings, which virtually ignores sun orientation has emerged. This is the all-glass skin building, found in most American cities and suburbs. Even those buildings which are not all-glass have tended to use larger amounts of glass than necessary for lighting or view. The primary architectural impetus for this design development has been sytlistic preference within the architectural design community and bears little if any relationship to functional requirements.

New energy codes coming on line in many states have already had the effect of reducing the amount of glass area being used and will probably continue to do so as their application widens.

Prior to considering the techniques for treating or protecting glass openings, consideration must be given to the factors which determine the size and location of the openings themselves. These factors are:

- NATURAL LIGHTING
- VIEW OUT
- VIEW IN
- NATURAL VENTILATION

NATURAL LIGHTING

In contemporary building design, daylighting is rarely considered as a functional concern. Its primary purpose is qualitative; to provide light and view on the part of building occupants. Just as interior comfort control relies on the mechanical system, rather that natural ventilation, lighting control is primarily dependent on the electrical lighting system, rather than the use of natural light. Where natural light is applied functionally, it is considered as supplementary or, if a primary source, is not usually designed analytically, but is treated as a redundent or back-up system. In this respect, the design of electric lighting is rarely modified (nor are heat load calculations made to account for its reduced use) as a function of the introduction of natural light.

In energy conservation design, the size and orientation of window openings and their effect on heat transfer may be measured against the energy demands for artificial light if the use of natural light is considered as a functional design element. In such instances, calculating the natural light as a usable source should affect the design of the artificial lighting system. The calculation must take into account the daylight available to fulfill the specified demand in relation to

- Daylight Hours @ acceptable intensities
  By Geographic Location and Season
- "Worst Condition" natural light availability
  -Cloud Cover

Any minimum acceptable intensity calculation must be guided by design policies which establish the acceptable light level at which various activities can be conducted. In this way a trade-off of energy demand can be calculated, balancing the effect on demand on the mechanical system caused by window openings against the effect on demand on the electrical system for artificial lighting. Obviously, the factors of this equation will be affected by geographic location and the compass orientation of the window opening.

VIEW OUT

Just as daylight is perceived as a socio-phychological need of building occupants, so is the opportunity to see out. While psychological data on access to light and view as a basic human need is inconclusive (there are publications supporting opposite conclusions), conventional wisdon, as tested in known market preferences, indicates that it is a strong demand. How much or little view access is necessary is an almost purely qualitative issue, unique to each individual design problem. In most instances it is determined either by the existence of a particular environmental feature in the immediate vicinity (a river, lake, mountain, ocean, etc.) or is a by-product of other design considerations (natural light, ventilation, building style, etc.). For the purpose of energy conservation analysis, view out must be considered as an incidental consideration.

VIEW IN

The location of window openings to permit view into the interior of buildings may be considered a necessary design element only in the case of retail merchandising buildings, where the purpose is display. Although this consideration is limited to a single building type, it accounts for a significant amount of construction. Display windows can be divided into two types; those which permit shallow display of small items and can be effectively sealed off from the main body of the store and those which permit a view of the whole sales floor. Although view-in differs from view-out by being an objectifiable requirement tracable to a specific need, it is similar in that its placement and amount is primarily determined by considerations other than energy conservation.

NATURAL VENTILATION

A primary determinant in the size, location and design of much of the fenestration in buildings, particularly residential structures, is the requirement for natural ventilation. Much of this is determined by building codes. While mechanical ventilation has replaced natural ventilation in many commercial and institutional buildings, natural ventilation is still the prevailing mode in residential construction. In most instances, during the heating season in cold areas, low occupancy allows for fresh air makeup space to occur through infiltration. A reduction in window opening size below prevailing code requirements to reduce heat transfer through the window areas would require the introduction of mechanical ventilation in residential structures. This alternative is not practical in houses and apartment buildings which depend on convection systems for heating, since it would entail the additional cost of a forced air distribution system. In housing which already uses forced air for heating and cooling (prevalent in much of the post-W.W. II suburban housing in the Central and Western U.S.) the reduction of infiltration loss and window area, with a forced air ventilating system incorporaing a heat exchanger may have considerable energy conservation benefits.

COMPASS ORIENTATION

Besides the size and amount of window opening; compass orientation is an important factor.

In northern locations, where heat loss through the windows during the heating season is the primary concern, concentration of fenestration on the south and west walls of the building is desirable - providing proper protection from direct sun impacts during the summer.

In southern locations, where heat gain is the primary concern, concentration of window openings along the north and east exposures is desirable.

If all of the openings could be concentrated at desirable orientations, depending on geographic location, the effect on direct solar heat gain may be seen in the following table:

WINDOW SURFACE TREATMENT

In many instances, window size and orientation is determined by factors other than energy conservation considerations. In such cases, treatment of the glass surfaces themselves provides a means for controlling solar impact.

Control of Heat Loss

There are three general catagories of heat loss through window openings.

- Infiltration - discussed under Section , Wind Control
- Radiation - Direct Radiant Transfer Through the Transparent Surface
- Conduction/Convection - Surface Transfer by Contact with Interior Air Currents

Radiation

Reducing heat transfer by reducing the radiant flow through glass surfaces is a special condition of glass technology. There are three primary techniques

- Tinting
- Polarization
- Reflectivity

A detailed discussion of the technical processes by which discussion. A table of the types of solar light/heat control glass currently available on the market place and their affects "on radiant transfer", updated periodically, is available from each of the major glass manufacturers or may be found in Sweet's architectural catalogue.

CONDUCTION/CONVECTION

The most prevalent technique for reducing conduction/convection losses is the employment of a thermal barrier. This involves a design assembly which breaks the direct physical contact between exterior and interior window surfaces, usually introducing a layer o of still air. In the glass surface itself, this ordinarily involves double or triple pane glass, sealed at the edges. For smaller openings, factory sealed galss edges, with a partial vacuum between the glass panes are available, but these alternatives are limited by technical constraints in the manufacturing process. Some consideration may be given to the use of inert gasses in place of the still air of the vacuum, but there is little data available on the practical application of this technique.

As in the case of glass design to respond to radiant transfer, a detailed discussion of thermal barrier techniques within the glass itself is not necessary for the purposes of this discussion.

b) SUN SHADING ON WINDOWS AND WALLS

Of all of the techniques for sun control, sun shading to intercept direct solar impacts on building surfaces is most subject to a broad range of specifically architectural/environmental design alternatives. In order to evaluate these alternatives in terms of their relative desirability in given situations, it is first necessary to identify the design objectives they are to serve. These may be divided into three major catagories of sun shading:

- HIGH-FREQUENCY VARIABILITY - Adjustment of sun shading on a daily or sub-daily basis.
- SEASONAL VARIABILITY - Adjustment of shading to respond to seasonal conditions. For instance, where it is desirable to have sun penetration in the heating season, but not during the cooling season
- FIXED CONTROL - Conditions under which there is no reason for desiring sun penetration at any time, such as in southern latitudes.

HIGH FREQUENCY VARIABILITY

Under conditions where it is desirable to admit sun penetration on a daily or sub-daily basis, fixed sun shading is not useful. In these instances, the most practical application of sun control is at the window surface itself. For this purpose shades, drapes or venitian blinds work most effectively. Conventially, this equipment is placed on the inside of the window surface. In this application its effectiveness is limited because the radiant penetration into the interior has already taken place and convection currents passing between the sun screen and the interior surface of the glass circulate the heat gain throughout the interior.

A more effective technique would be to place the sun control device on the exterior surface, in the form of shutters or adjustable horizontal louvers (like venitian blinds) which would deflect the sun prior to its penetration into the interior when it is undesirable, but could be drawn aside when sun penetration for heat gain is beneficial to maintaining desired comfort levels (passive collection).

SEASONAL VARIABILITY

In geographic areas characterized by cold winters and hot summers (such as the North Central United States, where the annual temperature swing in some regions varies in excess of 100°F) seasonal control is the most significant consideration.

These localities offer the opportunity for a wide variety of approaches to sun control.

Plant Material

While little if any measurement data exists on the temperature drop under the crowns of various deciduous shade trees in sunlight (none could be found in the literature search) it is common knowledge that they are an effective solar barrier. Not only do individual trees block out direct sun impact, but groves or stands consisting of a number of trees in close proximity will alter the microclimate in their immediate area.

The particular advantage that deciduous trees offer in climates with extreme temperature variations is that they block out sun penetration during the hottest part of the year and permit penetration during the heating season; in regions where it is continuously hot, they maintain their leaves and block out sun penetration year round.

While the lack of existing measurement makes it difficult, if not impossible, to discuss the application of trees and plant material on an analytical basis at this time, some gross assumptions may be made as to their sun control affects. In any event, it may be assumed as self-evident that the addition of deciduous tree cover will contribute to reduction of solar impact.

The collection of measurement data pertaining to the actual microclimatic changes effected by shade trees, particularly in respect to solar radiation, would contribute greatly to the available arsenal of energy conservation design techniques.

MANUFACTURED EQUIPMENT

Man-made sunshading for seasonal application varies from the equipment available for high-frequency use only in its relative mobility. While it is obvious that shutters, shades, louvered blinds and drapes could be maintained in proper positions for seasonal control, their real purpose is to deal with immediate needs - usually at the sacrifice of visibility - and they are too easily adjustable to be considered reliable control devices in determining the energy demand for design purposes. On the other hand, heavier, less adjustable equipment, such as demountable fixed awnings and sunshades, removable screens and other sun control devices which are usable on a seasonal basis, but are too cumbersome to be employed or removed on a daily or sub-daily basis, can be assumed as part of a predictable and reliable sun control system.

A good example of seasonal control devices is a metal window screen material manufactured of tiny louvers available at a variety of preset angles. This material can serve both as an insect screen and a sun barrier. One trade name for this product is "cool shade".

Another more general example is the seasonally demountable fixed aluminum awning available through various retail hardware distribution centers all over the United States.

FIXED CONTROL

Fixed sun control may be defined as elements which are integral to the structure itself and are not removable under ordinary circumstances. Obviously, the seasonal control components cited in the previous sub-section may be treated as permanent attachments. But in the context of this catagory only those elements which could not be removed without actually altering the structure itself could be considered fixed control.

Examples of fixed sun control are roof overhangs (Fig. 9), vertical fins perpendicular to the exterior wall surfaces at window openings and horizontal or louvered trellises over window openings (Fig. 10). These last devices can be designed, by altering the angle and spacing of the louvers, to admit sun penetration at pre-established sun elevations, when heat gain is desirable, and block it out when it is not.

The reason for distinguishing among the different kinds of sun control devices applied to building fenestration is to establish a basis for incorporating solar impacts in calculations of energy <u>demand</u> for heating/cooling purposes in designing for energy <u>supply</u>. One characteristic of the architectural/environmental control devices discussed is their measurable ability to reduce direct load on building surfaces; the other is the reliability with which they may be expected to properly be maintained in place. The traditional approach to calculating energy needs as affected by architectural/environmental sun control devices has been to ignore them altogether or to incorporate only those which are fixed and permanent, such as roof overhangs.

What the preceeding discussion suggests is that, in the interests of a more refined approach toward energy conservation, both the high-frequency variable and seasonally variable control devices be incorporated into the design calculations (on the demand side) for energy system. This application would assume reasonable predictions as to appropriate use of the devices and would accept deterioration in the performance of the total system if this is not done. In other words, if the shades, screens, awnings, louvers, etc., are not properly adjusted, the mechanical system would, by design, not have the capacity to make up the difference necessary to achieve the desired comfort level.

c) ENVELOPE SURFACES

While attention to the amount and orientation of building fenestration and the use of sun shading on windows and walls will account for a considerable amount of direct sun effects, there remain surfaces of the building envelope (walls and roof) which are neither

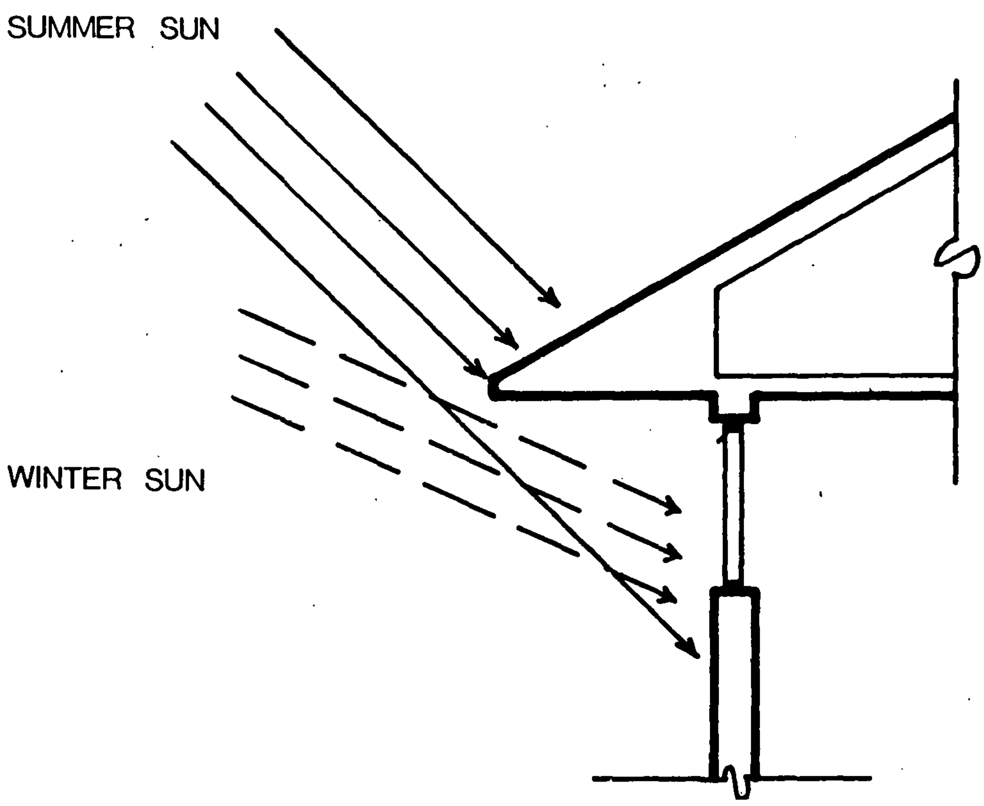


FIGURE 9

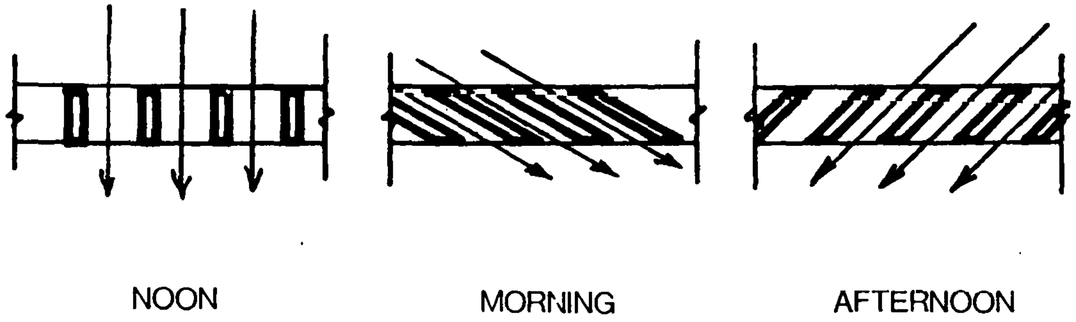


FIGURE 10

fenestrated or shaded. Aside from the consideration of these areas as solar barriers by construction and/or insulation, some consideration should be given to the treatment of their exposed surfaces. The two most obvious considerations in this respect are color and mass.

Color

Traditionally, in contemporary buildings, the roof and wall color of buildings has been either the incidental result of the natural color of the particular building materials employed or, where coloring materials (paint or stains) are applied, they have been chosen for decorative affect.

Historically, this has not always been the case. In warm climates masonry buildings have been characteristically painted white or whitewashed to reflect heat.

To the extent that heat transmission through building materials is a factor in total heat gain, the color of the material can influence this affect. This is particularly true of roof surfaces in low-rise buildings, which receive the most direct solar impact and which account for the most effective transmission area. Since exterior building materials are available to both extreme ends of the color range, from coal-tar products to glass, the application of materials with particular attention to their capacity to absorb or reflect radiant energy may be an important consideration in the design process.

d) THERMAL MASS

In conjunction with the color of exterior surfaces, the capacity of building envelope materials to store heat may have a significant affect on the energy demand required to adjust interior spaces to exterior conditions. The effectiveness of mass materials to slow the process of heat transfer has been understood and applied for many centuries. Thick-walled buildings, particularly in hot climates, were built in pre-industrial societies not only because they expressed a particular level of economic and technological development, but also because experience demonstrated their effectiveness in maintaining relatively cool interior temperatures, even when exterior temperatures were very high.

With the arrival of the industrial era, as rising labor and transportation costs made ease of handling and speed of erection increasingly more economical, lighter wall and roof assemblies were developed and light weight insulation materials were introduced to retard heat transfer. While these materials are relatively effective in retarding direct heat transfer, they have no thermal storage capacity.

While the reintroduction of mass-wall construction may not be practical on the basis of pre-industrial hand labor techniques, it is not necessarily a labor-intensive or energy-intensive process. Thin-shell assemblies with the capacity for retaining the earth fill available on most construction sites to create walls which by sheer thickness achieve similar U factors to efficient contemporary insulation materials and have the added advantage of creating the thermal lag necessary to "even out" the effects of exterior temperature changes on interior spaces may contribute significantly to the reduction of energy demand (Fig. 11).

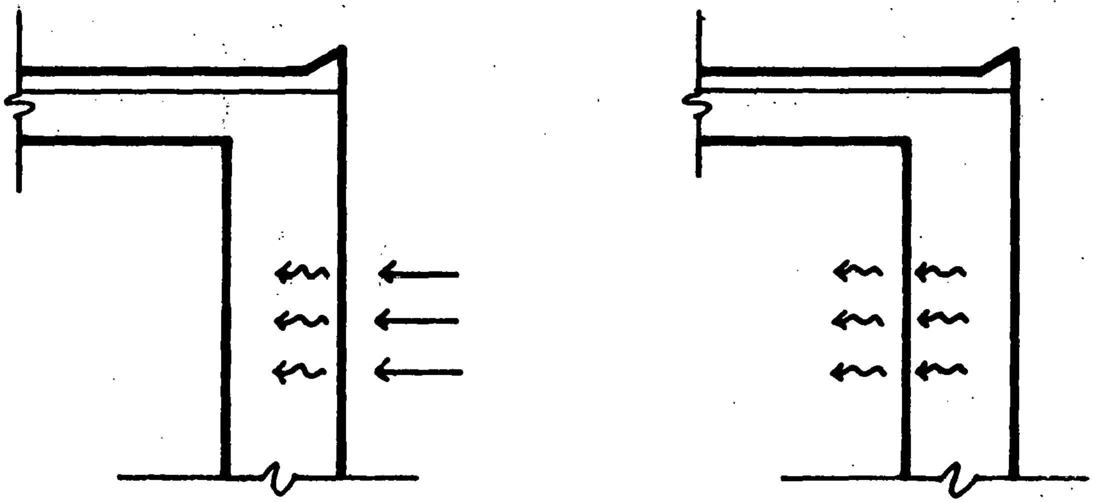
SUMMARY

The preceding discussion of sun control considerations in energy conservation design has identified a number of considerations which may have a significant impact on reducing energy demand to achieve acceptable interior comfort levels. Their incorporation in design approaches utilizing alternative energy sources may have a significant impact on the cost-effectiveness of those sources - particularly solar heating - by requiring less equipment to meet performance requirements. The two primary effects will be:

- Reduction in heating demand by passive solar collection
- Reduction in cooling demand by reducing direct solar impacts

The particular considerations which have been identified are:

- Reducing the number and size of glazed openings



DAY NIGHT

FIGURE 11

- Orienting building fenestration (glazed openings) in compass directions which are most effective for desired control of direct sun penetration
- Effective use of natural lighting
- Controlled ventilation
- Variable control of sun shading
- Control of exterior surface color and reflectivity
- Use of exterior walls for thermal storage

It may be noted that, as in other Sections, reference is often made to pre-industrial building design and construction. It is no accident that in the period of relative energy scarcity which constitutes the overwhelming bulk of building history, energy conservation design, probably learned by trial-and-error methods, had of necessity achieved a level of refinement which has been disregarded in contemporary construction. With the prospect of a re-emergence of energy scarcity it will serve us well to re-examine these techniques.

4 EARTH SHELTERING

Earth sheltered habitat is both the oldest and newest form of human shelter. Pre-historic cave dwellings were evidentally used because they not only offered security, but also the highest level of comfort available to primatives lacking little more than the most fundamental technological skills. They were apparently ultimately abandoned because their occupants had no means to satisfactorily modify their size, shape, orientation, ventilation and relative humidity, but more importantly because they could not be moved to favorable locations for hunting, gathering and finally agricultural opportunities.

Their use, however, is not limited to pre-history. Cave dwellings in American southwest were occupied as recently as 600 years ago and man-made caves, cut out of natural rock formations, are currently occupied as dwellings in various parts of the world; Tunisia, China, Ghana and Turkey.

Contemporary interest in earth sheltered environments reflects some of the same considerations which have made them attractive since pre-historic times. The earth is a temperature-stable medium. Compared to atmospheric conditions which can vary in temperature as much as 140°-150°F seasonally and 40°-50° daily in some relatively heavily occupied areas of the United States; sub-terranian temperature at relatively shallow depths vary less than 10°F annually and daily variations are not worth remarking on. What is more, average sub-terranian temperatures are within 15°F of conventional comfort levels.

With the availability of contemporary technology to shape sub-terranian spaces to almost any conceivable specifications and to provide ventilation, artificial lighting and humidity control, earth sheltered spaces would appear to provide near-ideal conditions for maintaining human comfort at reduced energy demand.

The term "Earth-Shelter" may refer to a number of conditions, all of which have in common the use of the natural earth as a part or all of the exterior envelope. The range of earth sheltered spaces would include:

- Ground-level structures with banked earth walls
- Partially depressed structures
- Structures set in slopes
- Fully depressed structures with earth cover
- Deep caverns.

The primary deterrent to the increased use of underground space is public acceptance. The anticipated level of acceptance may be related to building types and the activities they contain. Some of these, although they are currently constructed above ground, have no need of access to natural light and ventilation. Others require direct outside exposure. A suggested classification of building types by requirement to outside exposure, based on public familiarity and experience, appears below

BUILDING TYPES WHICH REQUIRE NO OUTSIDE EXPOSURE

- Storage and Warehousing
- Light Manufacturing
- Stadia
- Theatres
- Retail Merchandising

BUILDING TYPES WHICH REQUIRE SOME OUTSIDE EXPOSURE

- Schools
- Office Buildings
- Transportation Facilities
- Heavy Industry
- Public Service Buildings
- Low Density Housing

BUILDING TYPES WHICH REQUIRE MAJOR OUTSIDE EXPOSURE

- Outdoor Recreation Facilities
- High Density Housing

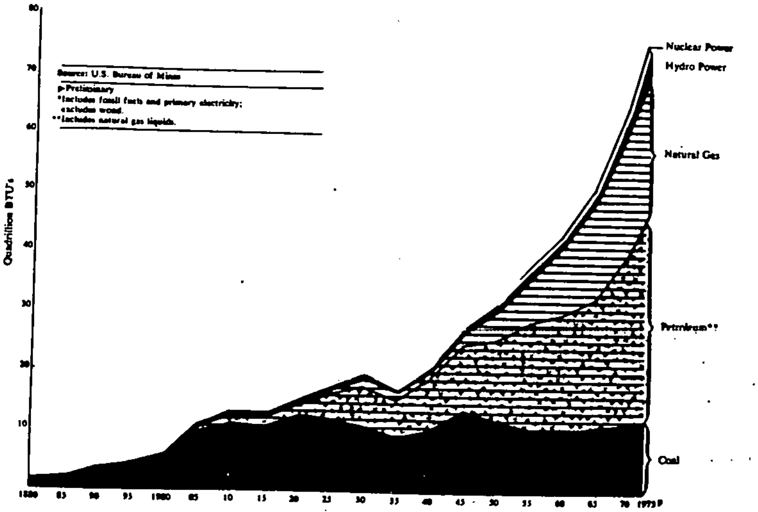
As can be seen, the vast majority total volume of usable space for all building types could just as well be constructed below ground as above.

A comprehensive description of the energy conservation characteristics and design application potential of earth sheltered construction is included in a paper, prepared by Dr. Thomas Bligh, University of Minnesota, reproduced in its entirety below.

A COMPARISON OF ENERGY CONSUMPTION IN EARTH COVERED VS. NON-EARTH COVERED BUILDINGS

ABSTRACT

Underground and earth covered construction offers a real and significant opportunity for saving energy and for preserving valuable land resources. These methods lend themselves to mass production thechniques without the adverse effects of endless visible repetition and can effect an energy savings of 75% or more.



Source: U.S. Bureau of Mines
p-Preliminary
*Includes fossil fuels and primary electricity; excludes wood.
**Includes natural gas liquids.

Figure 12. Energy Consumption in the U.S. by Sources*. Selected years 1880-1973 (from Reference 1).

Energy Conservation by Building Underground in Underground Space, Vol. 1, No. 1, 1976, Author - Thomas Bligh

ENERGY REVIEW

Figure 12 is presented simply as a reminder of the present situation and future trends. By now it should be quite clear that continued growth in this manner is untenable. It is worth noting that coal production has remained essentially constant since 1905 as oil and gas increased. From now on as oil and gas production continue to decrease, having peaked in the U. S. A. in 1970, as shown in Figure 13, coal production will have to increase once again, along with other potential sources of energy.

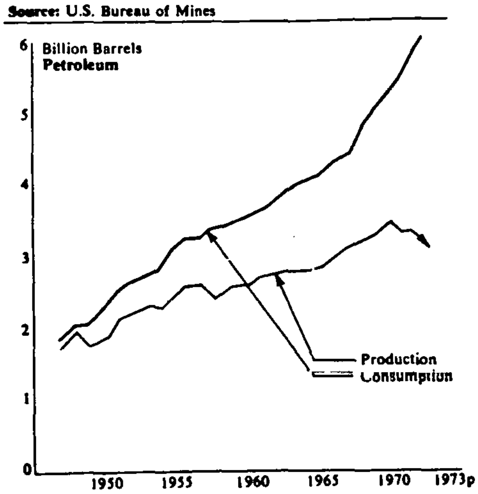
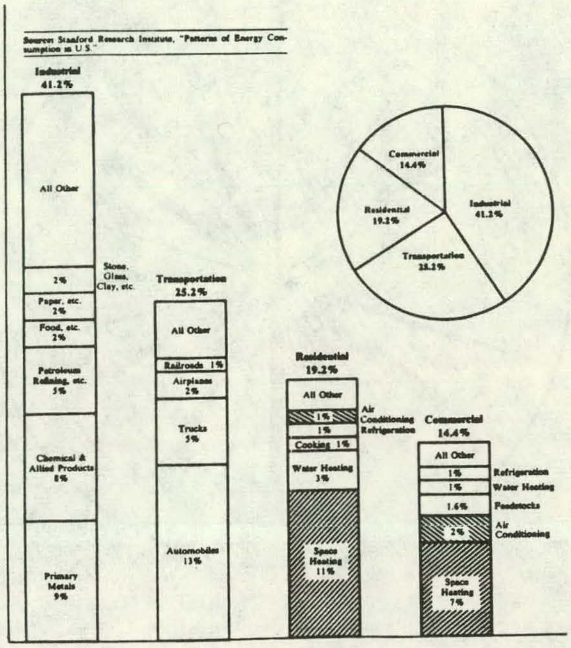

Source: U.S. Bureau of Mines

Figure 13 U.S. Energy Production and Consumption 1947-1973 (from Reference 1).

The problem of increasing this production substantially is monumental considering the shortage of miners, skilled managerial personnel and the huge amounts of capital investment needed.

Increasing conventional energy sources is at best a short term solution. An energy unit produced is burned but once, leaving only its pollution (thermal and chemical). An energy unit conserved represents a permanent reduction in demand, and it is pollution free! Every possible effort should be made to reduce our energy requirements.

What is the potential for saving energy by better building design? Figure 14 shows the total U.S.A. energy end use. Space heating alone accounts for some 20% and air conditioning some 4% of the total. Space heating and cooling thus accounts for almost 25% of the total U.S. consumption (as much as the whole of transportation) and the potential for savings is very large indeed.



Source: Stanford Research Institute, "Patterns of Energy Consumption in U.S."

Figure 14. Total End Uses of Energy in the U.S.A., 1968 (from Reference 1).

For the residential sector alone, space heating accounts for 65% of all residential energy with a further 5% for space cooling. The residential breakdown for energy use is shown in Figure 15 Space heating and cooling is by far the largest component of energy use in this sector, and this alone accounts for almost 16% of the nation's total raw energy use and is supplied primarily by natural gas and petroleum products, the energy sources in the most critical supply position at present. It is worth noting that Figure 4 represents the nation's average so that space heating in the cold northern states will require considerably more than shown and their situation will be particularly vulnerable.

Szego (1971) reported the detailed energy outflow from a 142 square meter (1500 sq. ft.) well built house in Washington, D.C. (using 4626 F degree-days). The energy outflow is mainly through sewers, garbage, solid waste, chimneys and vents, and heat losses.

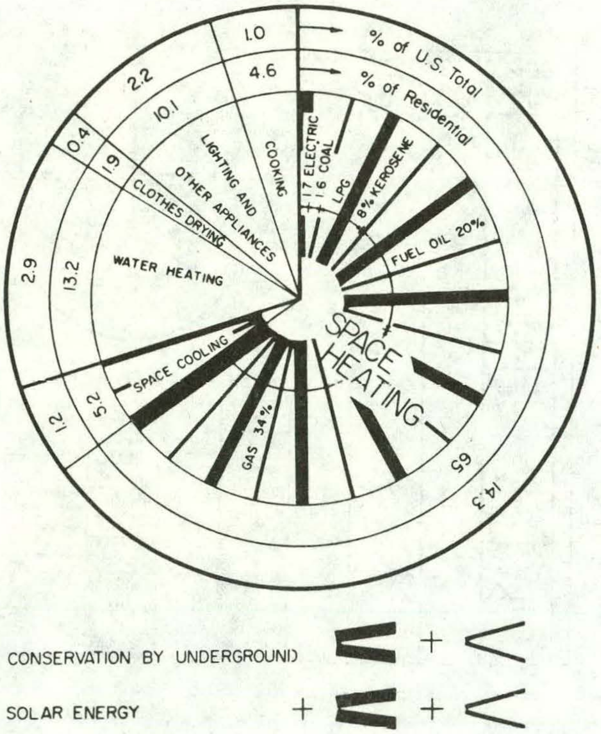


Figure 15. Residential Energy Usage Cake (1970 data compiled from References 2 and 3).

CONSERVATION BY UNDERGROUND

SOLAR ENERGY

RESIDENTIAL ENERGY USAGE CAKE

Of these the heat losses per household are due to:

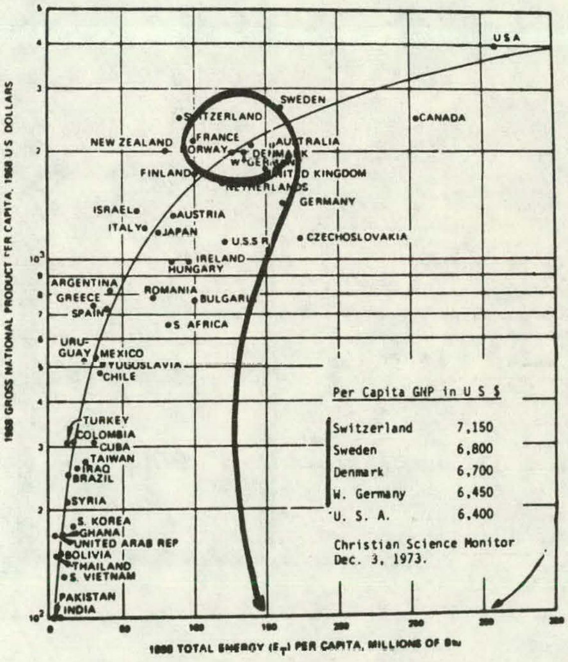
1) Heat transmission, through the walls, ceilings, floors, doors and windows, which amounts to 85.7×10^6 kJ/yr (81.2×10^6 BTU/yr)

2) Air infiltration into the dwelling, through cracks, around windows and doors, and due to door openings, which amounts to 20.4×10^6 kJ/yr (19.3×10^6 BTU/yr)

These together constitute 79% of the energy outflow from the house (transmission = 64% and infiltrations = 15%.

During the summer the opposite effect occurs and the house receives heat gains from transmission and infiltration (which also adds excess humidity). As will be shown later, a great deal can be done to dramatically reduce the unwanted heat losses or gains.

Figure 16, from reference 2 with a few adjustments, shows the Gross National Product per capita vs. energy per capita and illustrates how the energy per capita increases with increasing GNP, but with diminishing returns. After adjusting to the December 1973 values, we find a group of countries in the left hand circle at about the same GNP/capita as the USA. The salient point is that the USA uses twice as much energy per capita as does the left hand group to maintain essentially the same GNP/capita. This surely indicates that there is indeed plenty of room for a move to the left in the USA.



Per Capita GNP in U S $

Switzerland	7,150
Sweden	6,800
Denmark	6,700
W. Germany	6,450
U. S. A.	6,400

Christian Science Monitor
Dec. 3, 1973.

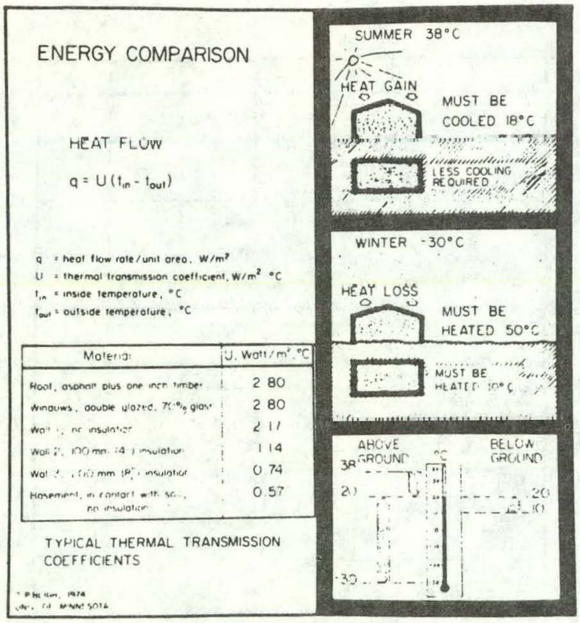
Figure 16, Gross National Product per Capita vs. Total Energy Consumed per Capita in 1968 (from Reference 2 and Christian Science Monitor, 3 Dec. 1973).

WHY UNDERGROUND OR EARTH COVERED?

Energy is wasted by unwanted heating or cooling of the surroundings. By reducing heat transferred to and from the surroundings, less energy is consumed to maintain desired conditions. The heat loss (or gain) from a structure principally depends on:

- The ventilation load for heating or cooling intake air (including infiltration air) and
- Heat transmission through the structure envelope.

The infiltration losses are reduced greatly or eliminated by underground construction since most walls are surrounded by earth and heat recovery systems then can be used more effectively.



ENERGY COMPARISON

HEAT FLOW

$$q = U(t_{in} - t_{out})$$

q = heat flow rate/unit area, W/m²

U = thermal transmission coefficient, W/m² °C

t_{in} = inside temperature, °C

t_{out} = outside temperature, °C

Material	U, Watt/m².°C
Roof, asphalt plus one inch timber	2 80
Windows, double glazed, 70% glass	2 80
Wall 1, no insulation	2 17
Wall 2, 100 mm (4") insulation	1 14
Wall 3, 200 mm (8") insulation	0 74
Basement, in contact with soil, no insulation	0.57

TYPICAL THERMAL TRANSMISSION COEFFICIENTS

* P. H. [illegible], 1974
Univ. of Minnesota

Figure 17. Heat transmission losses for above and below ground structures. (NOTE: The U values, given here in sl metric units, were calculated from ASHRAE[4])

The transmission losses, illustrated in Figure 18, depend on:

- The insulation, as measured by the thermal transmission coefficient U which measures the ease with which heat is conducted through the wall of the structure (including surface effects) so that the smaller the U factor the better the insulation and the smaller the heat loss rate, and
- the temperature difference ($t_{in} - t_{out}$) between the inside and outside of the structure.

Figure 6 lists some U factors, from which it can be seen that the U factor for an underground wall with no insulation is comparable to or better than the best above ground insulation. Soil requires no manufacturing energy unlike artificial insulation such as glass wool.

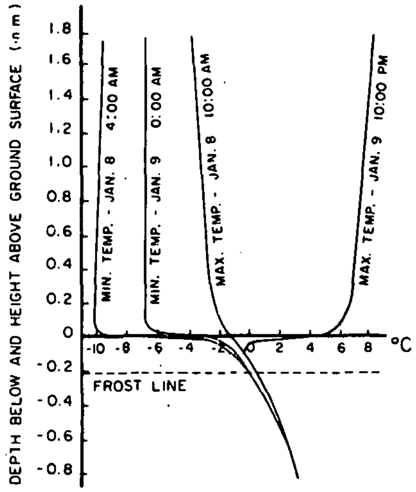


Figure 18. Maximum and Minimum Tautochrone, January 8-9, New York Metropolitan area, 1950 (data from Reference 5)

Above ground the temperature difference is determined by the local weather conditions. On the other hand, the earth smooths the temperature fluctuations both on a daily and yearly basis. Seasonal temperature fluctuations of the soil reach a depth of several meters whereas the penetration of short term temperature fluctuations over periods of hours or days is almost negligible. The short term fluctuations are illustrated in the tautochrone given in Figure 18. The wide surface fluctuation essentially is eliminated below 0.2m (8 inches); this demonstrates the advantages of even 0.2m of earth cover, for example a sod roof.

At greater depts, soil temperatures respond only to seasonal changes and the change occurs after a considerable time delay. This is shown in Figure 19 for the Twin City area. The amplitude of the mean temperature fluctuation decreases reapidly with depth. At 5 to 8 meters the temperature varies only slightly from the average yearly temperature for that location, which is about 10°C (50°F) for the Twin Cities.

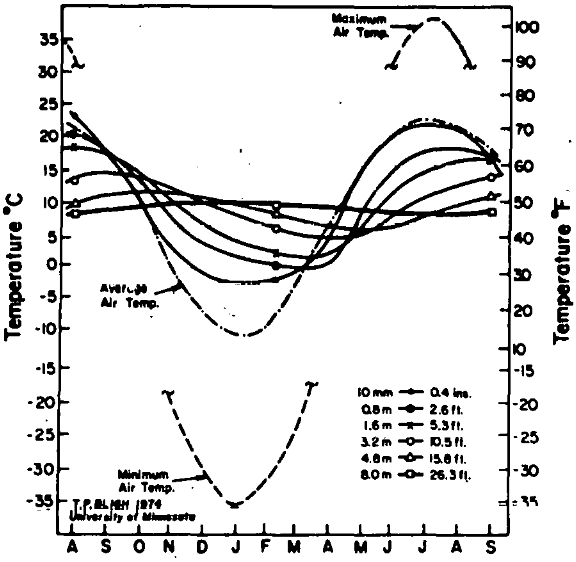


Figure 19. Average monthly temperature variation with soil depth near St. Paul, Minnesota (data from Reference 6 and E. Bowers, University of Minnesota).

It is worth commenting on the temperature phase-lag, which increases with depth so that during periods of highest surface temperature, June to August, the ground temperature at 8 meters is at a minimum and vice-versa for periods of low surface temperature. The advantage is insufficient to be of any practical use.

The transmission heat loss rate through above ground walls having different glass wool insulation thicknesses and that through and uninsulated basement wall for various outside temperatures is shown in Figure 20. Clearly, when the outside temperature is 20°C (68°F) no heat flows through an above ground wall if the inside temperature is 20°C. For any wall, as the outside temperature decreases the heat loss rate is negative indicating a heat gain. Note that there is always a constant slight heat loss in summer and winter from an underground building. In the case of a house this rate is about that required since people, cooking, lights, etc. produce excess heat. The common experience of basements being pleasantly cool in summer (though a small amount of dehumidification sometimes is required) and warm in winter with little or no heating confirms this.

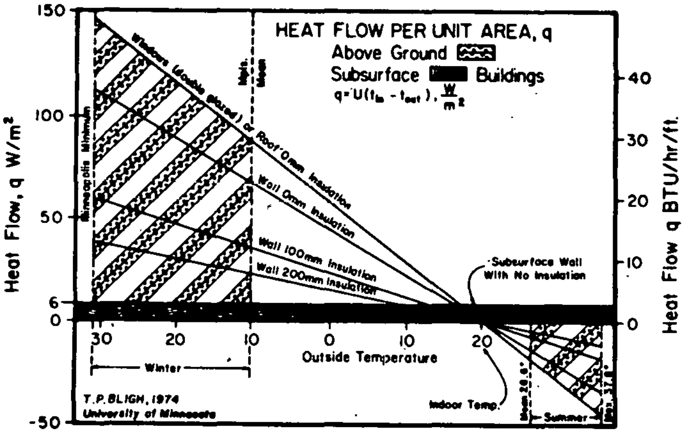


Figure 20. Heat flow rate for unit area for above and below ground buildings.

For example, on a cold winter's day of -30°C (-22°F) the heat loss rate per unit area will be 6.5 times greater above ground for a wall with 200mm. (8 inches) of insulation and 10 times greater for a wall with 100 mm (4 inches) of insulation compared to an uninsulated wall underground. The situation will be even worse if the wind blows, since above ground a wind chill factor increases the heat loss (and infiltration); underground the wind has no effect.

In no way can improved insulation on an above ground building begin to compete with subsurface structures from an energy conservation standpoint.

ENERGY CONSUMPTION COMPARISON

The figures in this section are based on data reported in Bligh and Hamburger[7] (1973); the original source references are also given.

As we have seen, energy can be saved since underground the insulation is good and the temperature varies only slightly from the yearly average temperature and hence, less heating in winter, and less cooling in summer is required. In addition, subsurface construction avoids direct sun radiation which, in summer, can contribute significantly to the cooling load,; in winter, wind chill and excessive infiltration are avoided.

surrounding mass acts as a heat sink retaining heat or cold so that standby refrigeration equipment is unnecessary. Cooling plants can be shut down for many days for maintenance and repair or due to local power failures without adverse effects on frozen foods. (In underground cold storage facilities in Kansas City, for example, temperature rises of typically 0.6°C (1°F) per day after plant shutdown are reported. Similar above ground facilities rise 0.6°C (1°F) per hour and in this case, standby equipment is imperative.) In many instances the cooling plant can be run during off peak periods resulting in substantial further cost savings.

1. Underground Storage and Refrigeration

The experience of Spacecenter Inc.[8] who operate similar facilities underground in Kansas City and above ground in St. Paul, Minnesota is shown in Figure 21.

Installation costs are lower for the underground simply because you require smaller plants. Note that energy is required to produce raw materials for and to manufacture, the cooling equipment so that in an overall view the smaller plant requirement contributes to the conservation of National Energy.

The energy consumptions are reflected by the operating costs which for underground are typically one-tenth those for above ground facilities. In addition to this, capital outlay is reduced considerably because of the smaller units required.

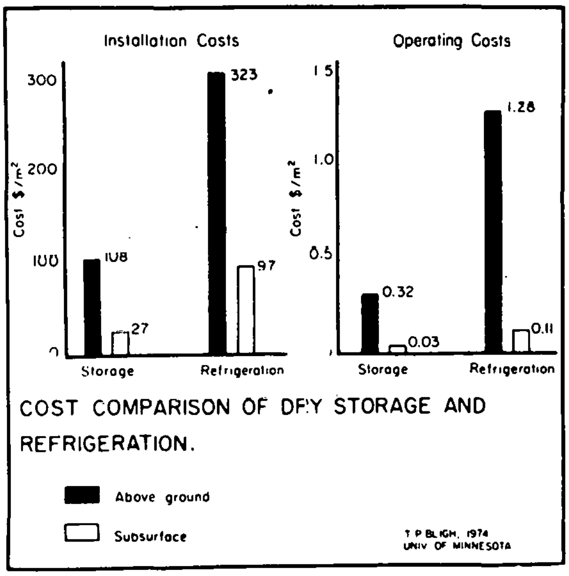
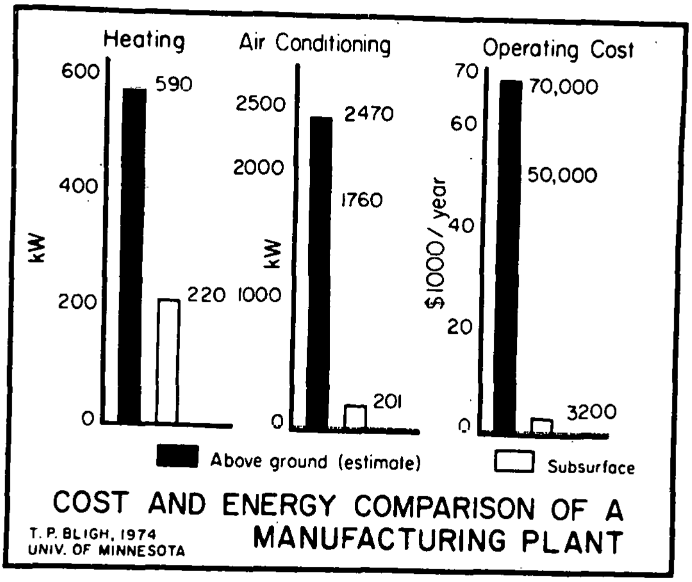


Figure 21. Cost comparison of dry storage and refrigeration for Space Center Inc. (data from Bligh and Hamburger, 1973; note costs are for May, 1973 before the energy price increase)

Initially the vast mass of rock surrounding an underground building must be cooled or heated to the operating temperature. Hence, excess capacity is required during the first year to so. This should normally be supplied by portable units which are subsequently removed, when a steady state condition is reached.

2. Underground Manufacturing

The experience of the Brunson Instrument Company[9], a precision instrument manufacturer, is cited in Figure 22. It is interesting to note that this facility was placed underground because of the great stability - no vibration* and stable temeprature and humidity conditions. Delicate instruments and machines need not be isolated (an expensive and difficult task) and they remain accurate, due to the extremely stable conditions, for much longer without realignment. This is of particular significance for the micro-electronics industry.



COST AND ENERGY COMPARISON OF A MANUFACTURING PLANT

T. P. BLIGH, 1974
UNIV. OF MINNESOTA

Figure 22. Cost and energy comparison of the Brunson Instrument Company[9], a precision manufacturing plant (data from Bligh and Hamburger, 1973; note costs are for May, 1973, before the energy price increase).

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* Much of the vibration experienced by above ground structures results from surface ground waves whose amplitude is a maximum at the surface and decreases rapidly with depth.

B.2 CONSERVATION DESIGN

B.2.1 SITING AND ORIENTATION

a. Wind Control: Plant Material/Trees
Topographical Shelter/Earth Berms
Built Shelter/Walls

b. Heat Sinks/Courtyards

c. Portal Orientation

B.2.2 BUILDING GEOMETRY AND ACTIVITY ORGANIZATION

B.2.3 SUN CONTROL

a. Fenestration

b. Sun Shading on Windows and Walls

c. Envelope Surfaces

d. Thermal Mass

B.2.4 EARTH SHELTERING

At that time, the Brunson Company had 13,000m^2 (140,000 ft.^{2}) floor area and 125 employees. At full capacity they will employ 500 people and install more machines in the same area. They estimated that under this expanded condition, no more heating equipment will be needed, due to added heat input from people and machines, and that only two-thirds more air-conditioning plant will be required.

The operating costs are particularly low since the air conditioning plant is operated only during nights on off peak power to bring the temperature and humidity below that required. Due to the heat capacity of the rock, temperature and relative humidity of the air then slowly rise during the day.

There are many advantages of underground location in addition to energy and land conservation:

- Maintenance - everything underground is protected from wear and tear of weather extremes - wind, moisture, heat, freezing, etc., no roof or exterior walls to maintain.
- Stability - no vibration. Delicate machines and instruments need not be isolated on expensive foundations.
- Operating savings - machines remain accurate for much longer without realignment due to very stable temperature and humidity conditons.
- Strength - floor loads are almost unlimited. Heavy machinery does not require elaborate foundation support - e.g. in Kansas City the shale can be loaded to 21MN/m^2 (200/tons/ft.^{2}).
- Earthquake protection - vibration amplitudes are smaller and there is little or no structural shear stress, the primary cause of building failure in earthquakes.
- Utility savings - electrical utilities, water pipes, sewers and drains can be hung from the ceiling or put in shallow ditches as there is no problem of freezing.

3. Housing and Large Buildings

Substantial amounts of energy could be saved by greater use of sub-surface space for education, libraries, recreation, commerce and habitation. Technical changes, however, must be economically and socially sound, and must be implemented widely to have a significant impact on energy consumption.

The National Bureau of Standards, Building Environment Division, has calculated potential cost savings over the next 25 years if thermal transmission characteristics of new and existing housing units are upgraded. They predicted that the then 60 million dwelling units would increase to about 100 million if, of the existing stock, 3% are built and 1% are retired each year for 25 years. If heat transmission could be reduced by 50% in all new houses and by 10% in all exisitng houses, savings in energy and cost for the next 25 years are shown in Figure 23. These savings are for dwelling units only and do not include those from sub-surface manufacturing, commerce, storage, etc., which, in addition, could be substantial.

ccording to a recent ERDA publication,[11] "...during the 1975-85 period, 40% of ll space that will be in place in 1985 will be constructed." And in "The Nation's Energy Future",[12] they estimate that if half the new buildings built each year were to incorporate energy conserving designs which result in a 40% savings consumption (a figure easily attainable in underground buildings) a saving of 15% of the present total U.S. consumption would be realized at the end of ten years. The potential for energy conservation by earth-covered buildings, therefore, is very large indeed.

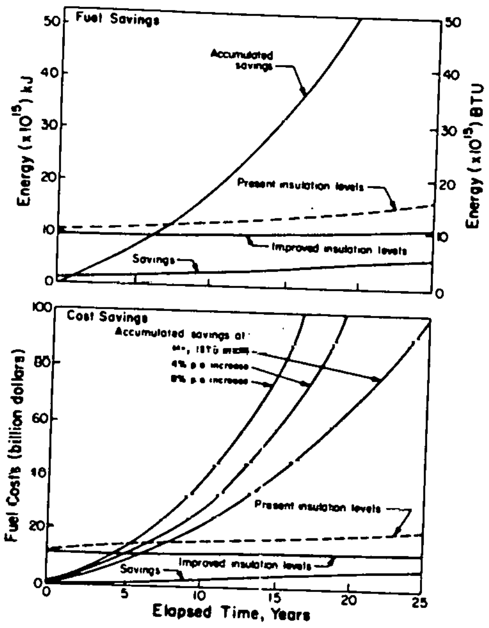


Figure 23. Energy and cost savings achievalbe by improved thermal design of dwelling units (from Reference 10).

Housing

Figure 24 shows the plan views of alternate versions of a preliminary design for earth protected houses, of 140 to 155m^2 (1500 - 1700 sq. ft.) floor area. The rooms surround and open onto a bright, sunlit court or atrium 5.5 by 7.3m (18 ft. by 24 ft.). The cross-section shows the dining room with the kitchen in the background and the glass French doors leading from the court into the bedroom beyond. Horizontal access to daylight elimanates any psychological feeling of being underground. The court provides a great degree of outdoor privacy and flows naturally into the surrounding parklike area.

The shell above and near ground level must be insulated well on the outside of the building to preserve the thermal mass within the building, and more important still, to prevent heat conduction up the walls, particularly if steel reinforced, to the surface air. A meter or so of earth on the underground roof would require strong and expensive beams. Therefore, the roofs should be covered by very thick insulation (possibly 0.3m of polystyrene or equivalent) with just sufficient soil to grow a lawn or vegetables.

By far the greatest heat loss from these buildings will occur through the windows and doors into the courtyard. These, therefore, must be well-sealed against air leaks and, for winter nights, have interior folding or sliding panels made of possibly 75mm (3 inches) polystyrene sheets. These panels could be plywood lined and framed or suitably finished and could be very appealing. (Of course, similar panels would reduce the heat loss from conventional housing dramatically.)

In a well-sealed building such as this, sufficient ventilating air would be introduced and exhausted. A heat recovery system would collect heat from the hot exhaust to warm the cold incoming air. In normal houses which have high infiltration losses, heat recovery is not effective.

The earth protected housing schemes shown in the following figures represent an attempt to solve three critical problems; the energy shortage, the increasing cost of housing and the preservation of open, green land space.

A typical city block is shown in Figure 25 with three-bedroom earth covered houses fitted together as shown in the previous diagram; the dotted lines indicate the house extremity below ground. Only a small section, the living room of each house is above grade and that would probably have a sod roof. Each house has its private outdoor courtyard and looks out onto the central parklike area. With suitable landscaping, the visual impact of each house can be reduced to a minimum as opposed to the blocked-in aspect of a typical townhouse scheme. The park areas from one block to the next are linked by bridges so that children can run, ride or cross country ski without crossing roads.

The diagonal scheme shown in Figure 26 is a small section from a large development. The roads would not be straight but would sweep to some overall landscaped plan.

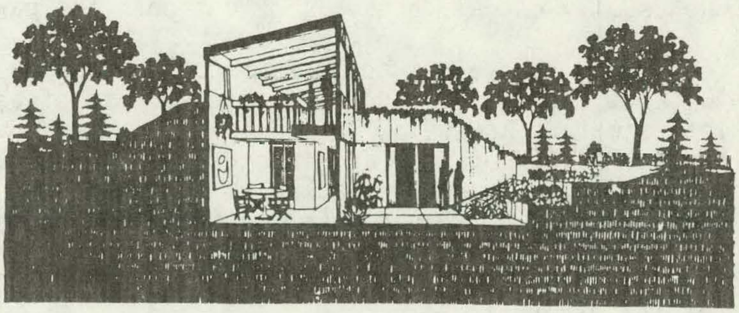
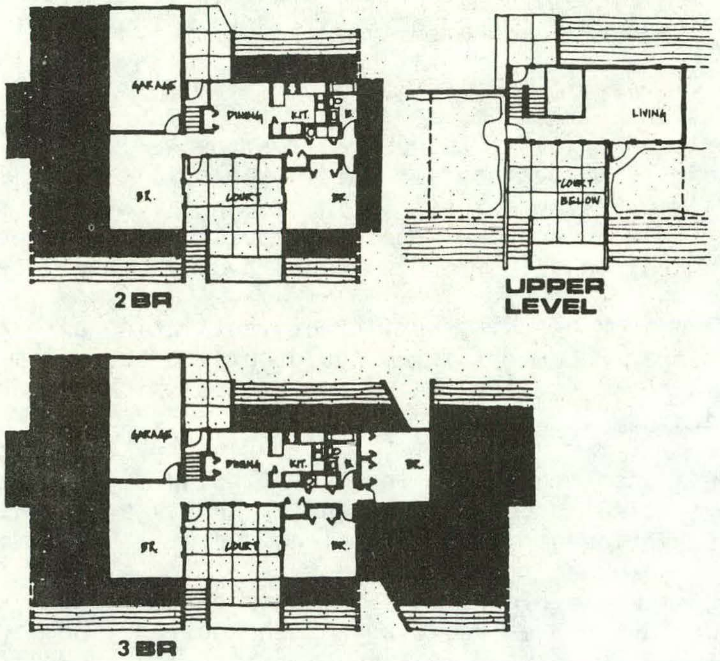


Figure 24a Earth protected house, a preliminary design (drawn by John Carmody).



2 BR

UPPER LEVEL

3 BR

Figure 24b Earth protected house, floor plan (drawn by John Carmody).

The dotted lines again show the underground building area surrounding the court which is overlooked by the above ground living room, shown striped. The corss-section below shows the house given in detail in Figure 24. Note that every house has at least 2 of the 3 open walls facing southwest or southeast so that all houses face the correct direction. Instead of looking at a blacktop road and another house, as we usually do, all houses look out onto the park.

These housing developments lend themselves to mass production - with its concomitant cost reduction - without the socially unacceptable effects of endless visible repetition (the identical sections are below ground level). The above ground living room and all internal designs can be architectured to individual taste. The houses in these high density designs are backed up to the roads, which are used for services as well as transit, leaving the continuous space between the houses as a parklike playground. Noise and vibration are reduced greatly by earth protection so that a high noise environment, such as near an airport, would have a minimum effect on the occupants.

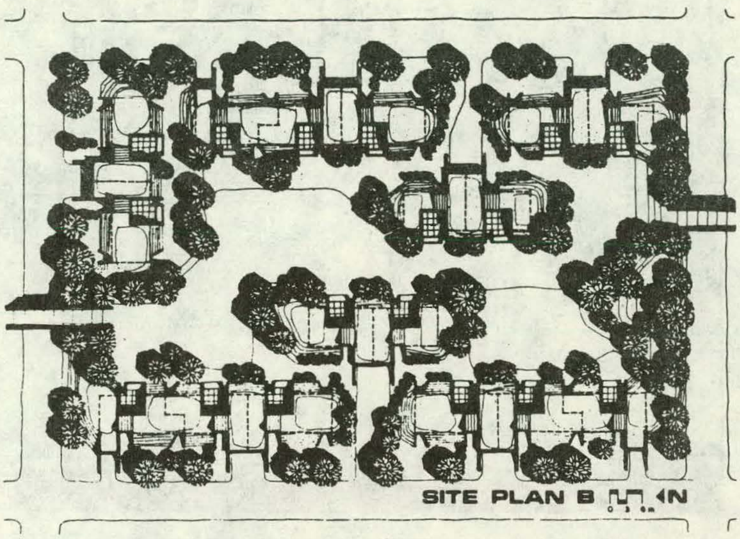


Figure 25. Plan view of a city block, high density earth protected housing plan (drawn by John Carmody).

In construction, trenches would be dug continuously by large machines, which greatly reduce excavation costs, the material being piled between the trenches. Utilities then would be trenched into the excavation floor, again continuously. Next, the houses would be assembled from prefabricated units using a mobile workshop. The house plan, Figure 24, shows the bathroom, kitchen, heating and washing units, back to back. This whole unit could be factory made, complete with plumbing, and simply connected in place; this is one of the most expensive sections of modern houses. Each bedroom likewise could be factory made and connected on site.

Once construction was finished the soil would be pushed back and bermed over the houses and the excess landscaped to turn a flat area into a beautiful, undulating playground. With less than one quarter the normal above-ground volume of houses visible, the area, less cluttered with buildings, would create a feeling of greater outdoor space.

A combination of such a housing scheme with manufacturing facilities below the houses appears particularly attractive. People then would walk a short distance and take an elevator to work. Lunch breaks could be spent at home or in the park and there would be no traffic jams or parking with which to contend.

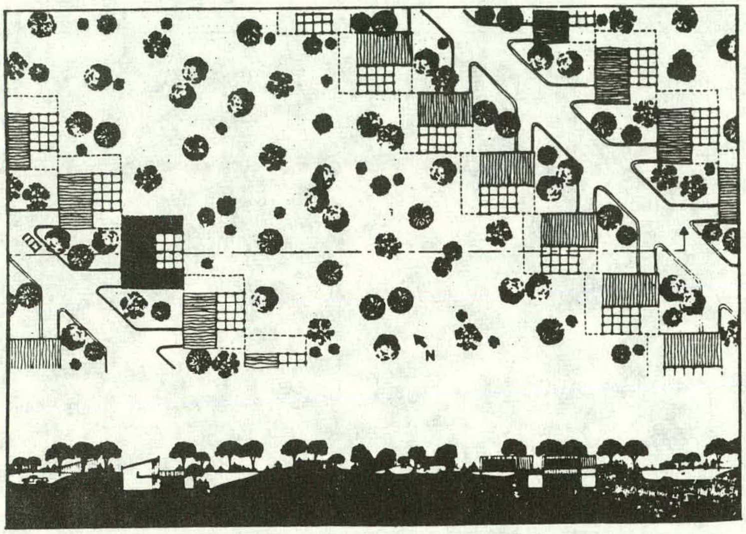


Figure 26 Plan and section of a high density earth protected housing development plan (drawn by John Carmody).

The high density development shown in Figure 26 has 14 units per hectare (=6 per acre) which is 21% more houses per unit area than the average for the four most dense residential areas in the Twin Cities (taken from aerial photographs) as shown in the following table:

	Land Area / House	Houses / Area	Green Area / Roof Area	Non-Blacktop / Blacktop Area
Diagonal plan Figure 15	712 m^2 (7664 ft^2)	14.0/hect. (5.7/acre)	10.7	8.9
Mpls-St. Paul high density residential	843 m^2 (9075 ft^2)	11.8/hect. (4.8/acre)	4.0	4.1

In spite of being 21% more dense, notice that there is 2 1/2 times more available green area in the diagonal development and that the blacktop (roads, etc.) area is less than half that of present residential areas, which would reduce snow plowing and road maintenance.

The house plan shown in Figure 26 has two bedrooms. This can be extended easily to three or four bedrooms by adding a bedroom extending towards the road behind the dining room/kitchen and also one below the garage (see Figures 13, 15). An additional bathroom could be placed below the garage. This plan, therefore, is extremely flexible without altering its advantages.

This development then, preserves open park-like space and could reduce costs substantially (building cost reduction, plus higher density). A small solar collector system easily could supply the hot water and marginal heating needs, and an ice air conditioning (see later) system, the cooling and dehumidification needs which would economically make these houses energy independent, except for cooking, lighting and appliances (see Figure 15), The energy needs would be reduced by some 84%.

What are the problems?

The psychological impact of any interior space should be an important consideration. In many cases the only difference between above and below ground space is the absence of a view (which, of course, is preserved in the underground houses discussed) and many above ground buildings such as stores, libraries, theatres, museums, laboratories, classrooms, and industrial plants are intentionally built without windows.

One of the few actual psychological studies in this area concerned the totally underground Abo Elementary School in Artesia, New Mexico.[13] The study concluded that not only were there no significant drawbacks to the school, but in some respects the learning environment actually was enhanced.

The social attitudes toward the use of underground space are related to the public's understanding of the environment. On a small scale, this was demonstrated by the community's total acceptance of the Abo School after some initial resistance. The social acceptance of underground structures will come about with the public's greater sensitivity to the preservation of land and energy resources and is dependent on the public being well informed and allowed to adapt to the concept. Thus, good demonstration projects are vitally important.

At present, there is undoubtedly a reluctance by lending institutions to finance underground buildings because of the lack of experience and fear of public unacceptance. They are concerned with initial costs and resale ability, rather than life-cycle costs. As energy prices increase, life-cycle costs will become more important and underground structures are bound to be viewed favorably. Once again, good demonstrations are imperative.

Underground construction in many instances is less expensive than equivalent above ground structures. John Barnard[14] estimates that his ecology underground-house building costs were about 25% less than the usual above ground frame construction; the house cost just over $206/$m^2$ ($20 per ft^2) of living space. The site work for the University of Minnesota Bookstore (including site clearance, excavation and hauling, sheet piling (E & W), backfilling and compaction and subsurface drainage exterior walls on a building of this type and size[15]. In urban areas particularly, the value of the excavated material may be an important consideration.

Finally, there is a dire shortage of good data for energy demand calculation in which engineers, architects and planners have confidence. Under the National Science Foundation's Energy Conservation program, we have a grant to fully instrument and study the new University of Minnesota Bookstore/Admissions and Records facility, a large building of 7700 m^2 (83,000 ft^2) floor area, 95% of which will be underground. This building, a cross-section of which is shown in Figure 27, will be completed in the fall of 1976. A sunken courtyard permits sunlight to enter all office space.

In order for the data to be more generally applicable, five different backfill materials will be used in discrete sections to represent as wide a range of soil conditions as possible. The temperature of, and heat flow through, the walls and surrounding soil will be measured. As an example, it is important to know how much of the heat goes through the wall and into the ground and how much goes up the wall (particularly through the steel reinforcing which is a high conductivity path) into those parts of the building which are exposed. The influence of nearby buildings will be determined and a careful total energy balance for the building calculated.

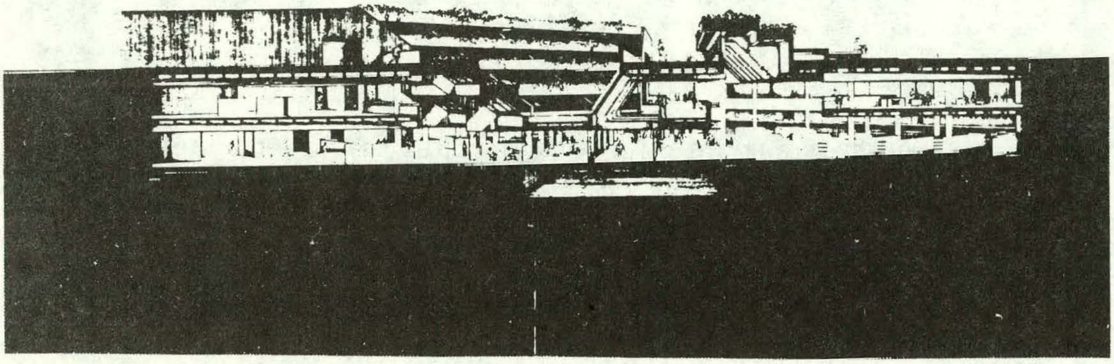


Figure 27. Cross-section of the University of Minnesota Bookstore/Admissions and Records underground building (the Myers and Bennett Architectural Studio/BRW).

A computer program is being developed to estimate the heating and cooling requirements for underground buildings. This model will be tested against the measured data and requirements of the bookstore, but will be set up in general terms to allow for as wide a range as possible of buildings, site conditions and climatic variations. The computer program would help smaller and technically less-expert builders meet new codes. Decisions of whether or not to place a given facility underground could be made more meaningful with a realistic estimate of the likely energy savings by subsurface location.

To indicate the energy efficiency of this building, we have an area, 5% of that of the floor area, available for solar collectors. Preliminary design calculations indicate that with this amll solar collector area, more than 100% of the heating load, and 25 to 50% of the cooling load can be supplied.

Towards Energy Independent Buildings

Figure 28 outlines a system in which winter cold can be stored for subsequent cooling and dehumidification during the summer. In this system antifreeze circulates from the copper pipe heat exchanger in a shaded area to the copper coil in the underground water tank. All through the winter the water is cooled slowly and frozen by the winter cold. The flexible insulation and plastic liner easily deform as the ice expands so that no stress is placed on the tank, and an inexpensive tank construction can be used. It is possible that the antifreeze will circulate naturally; if not, a small pump will be used. When the water in the storage tank has frozen solid, the valves are closed, and the winter cold remains in storage until summer.

When air conditioning is required, the chiller coil valves are opened, and cold antifreeze is circulated through the chiller coil which cools and dehumidifies the air in the forced-air duct exactly as does a conventional air conditioner.

The thermostat control would simply operate the pump. All through summer the ice slowly melts to water, air conditioning the building. At the end of summer, the chiller coil valves are closed and the other valves are opened ready to freeze the water during the following winter.

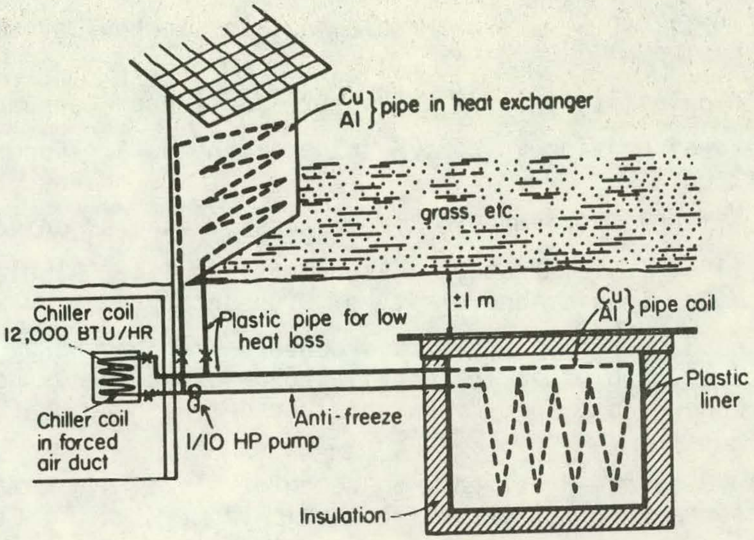


Figure 28. Energy independent air conditioning system. (University of Minnesota patent pending).

The chiller coil should be sized for the maximum cooling rate required. That shown in Figure 28 is for a 140 m^2 (1500 ft^2) house in Minneapolis. The total energy required for an entire summer cooling season was measured by Honeywell[16] over three summers. For the hottest summer (about 50% for cooling and 50% for dehumidification), the mass of ice required would be about 40,000 kg. or a tank 3.7 m (12 ft) high by 3.7 m (12 ft) in diameter. The heat gain by the ice storage over five months is less than 1% of the stored energy and can be ignored.

In climates not blessed wib sufficient winter cold, a small solar collector could run a small cooling plant to store ice throughout the winter. It is worth noting that no heat pump, which requires electrical energy and hence cannot be energy independent, is required. The technology is all simple and well established.

By combining the energy conserving aspects of underground construction with a small and hence economic solar collector system, the heating and hot water requirements of a building can be met. However, it is difficult to meet the cooling load unless a much larger and more expensive solar collector system is used. By storing winter cold in ice to meet the cooling load not supplied by the solar collectors, we have a real and economic possibility of designing buildings large and small to be energy independent for heating and cooling.

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