DYNAMIC RESPONSE OF CONVENTIONAL RESIDENTIAL CONSTRUCTION TO SOLAR RADIATION THROUGH WINDOWS DURING THE HEATING SEASON

Zulfikar O. Cumali A. Osman Sezgen
Robert Sullivan Robert I. Hossli

ABSTRACT

A significant potential for increasing the contribution of solar heating during the heating season has been overlooked. This increase can be effected by improving the orientation of standard windows and sliding glass doors in conventional low-mass residental buildings. Currently, building regulations do not provide incentives for placing more glass on south facing walls. There is no standard calculating procedure; hence, overheating may occur when glazed areas are too large for low-mass construction. The National Fenestration Council is sponsoring this study to develop recommendations for maximum glazing areas and to investigate the effect of this glazing on summer cooling loads.

This paper details the definition and structure of a comprehensive parametric study which treats the thermal response of a typical single family residence. A representative range of climate zones and geographical orientations, two floor structures and two air-circulation schemes are to be made in the course of an analysis which features a primary parametric on south facing window sizing. A modified version of the DOE-2A energy analysis program will be used in the study. It is intended that the results will yield sufficient data to support recommendations on optimum glazing areas for low-mass construction.

KEY WORDS

Building Simulation
Thermal Loads
Fenestration
Residential Energy Usage

INTRODUCTION

Solar radiation through windows is not being utilized effectively to supplement non-renewable heating fuel in most of the conventional homes being built today. First, builders have no incentive. As an example, current HUD and FHA Minimum Property Standards limit glazing areas to a maximum of 15 per cent of the gross wall area and a minimum of eight per cent of net habitable floor area, without regard to orientation.

Second, builders have no standard method of calculating solar radiation and net heat gain through residential windows during the heating season. The current ASHRAE method for estimating fuel consumption of residential buildings utilizes outdated calculations for "night-time" window U-values.

Zulfikar O. Cumali is the principal of Consultants Computation Bureau/Cumali Associates, Oakland, California; A. Osman Sezgen and Robert Sullivan are analytical engineers at CCB/CA; Robert I. Hossli is director of the Design & Development Department, Architectural and Building Products Division, Reynolds Metals Company, Richmond, Virginia.

Third, builders have no simple method to determine the maximum glazing area that will minimize the possibility of overheating. The relatively low mass of conventional wood frame construction does not provide adequate storage of solar radiation from large south facing windows in mild weather.

Consequently, there is currently neither an incentive nor a means for home builders to utilize principles of passive solar design, to safely increase southerly glazing, and to reduce the consumption of non-renewable heating fuel. The significant potential for increasing the annual solar heating contribution of standard windows and sliding glass doors in conventional low-mass residential buildings has been overlooked, although it is the easiest and fastest to implement as compared with other alternatives.

Table 1 shows the effect of current regulations and the potential for increasing annual solar contribution by optimizing southerly glazing. It is possible to change from a net heat loss for all glazing to breaking even or a net heat gain. An average savings of 8×10^6 BTU - equal to about 90 gallons of oil per year - could be achieved for a 1,232 square-foot home in St. Louis with 15 per cent glazing by having 60 per cent of it south facing as compared with other random orientations with the same total glazed area. This savings can be achieved with little or no increase in cost. About 30 per cent of the south wall is glazed in this example. The object of the current investigation is to determine how much more glazing area can be used effectively.

In addition to solar radiation, the window system also provides light, ventilation, egress and visual contact with the surrounding environment. Windows are a key design element, providing much of the character and appeal of a home. Improved utilization of south facing windows can be an important step for the residential building industry in shifting to energy conserving homes and the ultimate applications of passive and active solar systems.

The utilization of solar radiation through south facing windows is obviously not a new idea. However, when this project was conceived three years ago, we were unable to find quantitative data on the net solar heat available during the winter season for various window orientations and geographical locations. Further investigation failed to uncover calculation methods that were directly applicable to typical residential construction.

A first phase study, sponsored by the Architectural Aluminum Manufacturers Association (AAMA) Research Foundation, utilized a full year of hourly weather for ten major cities. It also included the development of a simplified calculating procedure and an analysis of the effects of solar radiation on a representative single family home. This study differed from previous investigations in that the computer program did not calculate and sum solar radiation above 60°F ambient air temperature. The objective was to reduce the possibility of overstating heat gain during mild winter weather and the fall and spring seasons. Heat loss was calculated using a static indoor temperature of 72°F. In the analysis of a representative single family home, solar gain was further reduced by approximately 37 per cent as an allowance for exterior shading and management of interior shades and drapes.

Results of this first phase study were presented at the January, 1979 ASHRAE meeting in Philadelphia and are available in the ASHRAE Transactions.[1] As compared with the standard method of estimating window performance, based on heating degree days, the calculated solar gain for homes with average window distribution indicates a potential for improvement of 29 to 30 per cent in Minneapolis and 41 to 48 per cent in Dallas, depending on house orientation. Double and triple glazed windows facing south are gainers, of course, except for locations where the combination of heating degree days and window U-value offset solar gain. The data of this first phase study has been summarized as a design aid for architects and builders that will be available from AAMA in early 1980.

The current second phase study is being sponsored by the National Fenestration Council (NFC), a newly formed organization of window manufacturers, glass producers and material suppliers. The main objectives of this phase using dynamic analyses methods are: 1) to develop recommendations for maximum glazing areas facing southeast, south and southwest in low-mass conventional residential construction, and 2) to investigate the effect of these maximum areas on summer cooling loads.

The National Fenestration Council is planning to work with the National Association of Home Builders (NAHB) to develop handbooks and design aids for architects, planners, homebuilders and engineers. This type of educational information and assistance is important to the successful implementation of the concept.

METHODOLOGY

The approach to the dynamic analysis is illustrated in Figure 1. The climatic variation is defined as the outermost looping element. Table 2 links the five climate zones to be analyzed and their respective degree day levels using a base of 18.3°C (65°F). Within this structure are contained the three primary calculation schemes. Initially, a set of space specific weighting factors will be generated to include those due to direct solar radiation, internal radiative components such as occupants and appliances, conductive heat gain/loss and variable space air temperature effects. These factors are independent of geographic orientation and thus will be defined for two distinct types of floors and ten window size combinations. A revision to the DOE-2A simulation program will determine the thermal loads within the residence.

Secondly, a geographic orientation loop has been defined as the outermost loop of the DOE-2A program. Three orientations (SE, S, SW) will be studied.

Initially, the constant space temperature LOADS portion of DOE-2A will be run to determine the load profile for each floor and window size; the third or SYSTEMS portion of DOE-2A will be run with an air-circulation loop to determine the variable temperature thermal loads. At this point, yearly space temperatures and load profiles will exist for a particular climate and orientation for 32 different residences based on the variable window sizes, floor structures and air-circulation schemes. Correlation and interpretation of the results will proceed from this point.

RESIDENCE DESCRIPTION/ZONING

Figure 2 presents a floor plan of the residence defined for use in this study. It corresponds to the structure defined in Reference 1, modified in accordance with details listed in Reference 5. The primary orientation of the building is such that the spaces with maximum fenestration are facing due south.

An excerpt from Reference 5 is shown on Table 3, which lists the maximum U-values for each of the surfaces for varying winter degree days. This table was used to size the surface layer descriptions presented in Tables 4 and 5. For the purposes of this study, it was decided to zone the residence into three spaces: a combined living room/bedroom zone of spaces having windows facing primarily to the south; a dining/kitchen area to the northwest; and a combined bedroom/bath to the northeast, as shown on Figure 3. The reason for this action stems from the primary southerly orientation of the fenestration, in that the heat transfer between spaces - in this case - would be from south to north, thus making unnecessary an east/west heat transfer among the living room and south facing bedrooms. In addition, a significant reduction in parametric possibilities occurs as a result of this action.

The decision has been made to vary the south facing window in the following manner: Eight sizes will be analyzed ranging from a low of 15% of the wall area to a high of 50%, in increments of 5% (Figure 4). The northwest facing dining/kitchen window will remain fixed at 20% of the wall area, and the northeast facing bedroom window will be fixed at 18% of the wall area (Figure 5).

It should be mentioned that these areas reflect the gross window size which includes framing. The clear glazing area is .877 times the gross area. Figure 6 shows a drawing of the residence with the minimum and maximum window sizes on the south wall and the fixed sizes on the other walls. Note also should be taken of the 2' overhang along the south and north perimeter of the building. This will include an additional shading effect into the results over and above the internal shading coefficient value of .37 for the roller shades, when these are implemented.

In addition to the above window parameters, two distinct floor constructions will be studied. The first consists of a hardwood floor over a two-foot crawl space above ground; the second is a concrete slab-on-ground. Also, the thermal loads and temperatures will be obtained with and without air-circulation.

Scheduling information for occupants, lights and appliances for each space and the total building is presented in Figure 7. These values were translated directly from results for a single family residence published in Reference 2. The figures represent percentages corresponding to the following daily totals:

a. Occupants: 24,200 BTU/day, where a human heat output of 400 BTU/HR/ADULT was assumed for 3.35 adults (2 adults and 2 school age children).

b. Lights: 13,580 BTU/day, where the value listed in Reference 2 (18,680/day) was corrected for building square footage. The total lighting available is equivalent to .52 watts/ft^2 or .64 KW.

c. Appliances: 55,300 BTU/day corresponding to a total available equal to 1.464 KW.

Comfort criteria and the assumed operating conditions to achieve it are as follows:

Heating below 68°F except during sleeping hours below 65°F.

Cooling above 80°F or if ASHRAE comfort level is exceeded.

The cooling unit comes on if 1) outside air is above 80°F, 2) blinds have been drawn on the sunny side at room control temperature of 75°F and the room temperature still rises to 80°F and/or 3) natural ventilation through controllable openings cannot keep room temperature below 80°F when outside air is above 60°F. The cooling unit also comes on if excessive temperature/humidity conditions exist to cause discomfort.

Sun control is via shading coefficient adjustment, which may correspond to a variety of devices such as blinds, shutters, etc. or in combination with fixed overhangs. Seventy-five per cent of all windows are assumed equipped with blinds, which are closed during evenings and controlled during sunlit hours. Ground reflectivity is assumed constant at 0.2.

CONCLUSIONS

A comprehensive parametric study is currently in progress involving the analysis of response characteristics of a single family residence to solar radiation through windows. This paper presented the methodology to be used in the analysis and also defined the structure and the various parameters to be investigated. A variation in climate zone, residence orientation, floor structure and air-circulation schemes in addition to the primary window size perturbations is planned to define the completion of the study.

REFERENCES

1. T. Alereza, R. I. Hossli, "A Simplified Method of Calculating Heat Loss and Solar Gain through Residential Windows During the Heating Season," ASHRAE TRANSACTIONS, Vol. 85, Part 1, (1979).

2. Hittman Associates, Inc., "Residential Energy Consumption Single Family Housing - Final Report," Report No. HUD-HAI-2, (1975).

3. DOE-2 Energy Analysis Program, Vols. I, II and III, Lawrence Berkeley Laboratory, Berkeley, CA., and Los Alamos Scientific Laboratory, Los Alamos, NM, (1979).

4. CCB/Cumali Associates, Interim and Final Reports - Passive Solar Calculations Methods, DOE Contract No. EM-78-C-01-5221, (1979).

5. HUD Design Manual.

6. Energy Design Manual for Residential Buildings, State of California, Department of Housing and Community Development, Division of Codes and Standards, Sacramento, CA, (1976).

7. ASHRAE Handbook of Fundamentals, ASHRAE, (1977).

TABLE 1. EFFECT OF CURRENT GLAZING REGULATIONS AND POTENTIAL FOR INCREASING ANNUAL SOLAR FRACTION

GLAZING AREA	GLAZING ORIENTATION	% OF ANNUAL FUEL CONSUMPTION		ANNUAL SOLAR FRACTION
		ASHRAE Method	Solar Method	%
8% of Net Room Area	Random*	17	10	8
15% of Gross Wall Area	Random*	29	17	14
15% of Gross Wall Area	60% South 15% East 15% West 10% North	29	0	25

*Except elevation with major glazing does not face South, window ratios are 0.5, 0.1, 0.3, 0.1 on respective sides.

NOTE: Estimates are based on a typical home having a gross floor area of 1,232 square feet and gross wall area of 1,152 square feet. A location in the St. Louis area would have 4,650 heating degree days. A double glazing system with a test U value of 0.60 is the basis for the calculations.

TABLE 2. CLIMATE ZONES

LOCATION	CLIMATE YEAR	MEAN ANNUAL HEATING DEGREE DAY
DALLAS	1964	2382
ATLANTA	1955	3095
ST. LOUIS	1949	4750
BOSTON	1961	5621
MINNEAPOLIS	1957	8159

TABLE 3. HUD RESIDENTIAL U-VALUE REQUIREMENTS

Maximum U Values for Ceiling, Wall and Floor Sections for Electric Resistance Heat (E.R. and Heat Pump or Fossil Fuel Heat (F.F.) (1)

Winter Degree Days	Ceilings (2)		Walls		Floors (3)		Windows		Sliding Glass Doors		Storm Doors	
(65°F Base)	E.R.	F.F.	E.R.	F.F.	E.R.	F.F.	E.R.	F.F.	E.R.	F.F.	E.R.	F.F.
0 - 1000	.050	.050	.08	.08	-	-	1.13	1.13	1.13	1.13	No	No
1001 - 2500	.040	.050	.07	.08	-	-	.69	1.13	.69	1.13	No	No
2501 - 3500	.030	.040	.05	.08	.07	-	.69	1.13	.69	1.13	No	No
3501 - 4500	.030	.030	.05	.07	.05	.07	.69	.69	.69	.69	No	No
4501 - 6000	.030	.030	.05	.07	.05	.07	.47	.69	.69	.69	Yes	No
6001 - 7000	.026	.030	.05	.07	.05	.07	.47	.69	.69	.69	Yes	No
7001 +	.026	.026	.05	.05	.05	.05	.47	.47	.69	.69	Yes	No

Notes

(1) For areas of 5000 winter degree days (WDD) or less, houses using heat pumps may be insulated to levels required for fossil fuels. In areas above 5000 WWD, houses using air to air heat pumps with electric resistance supplemental heat shall be insulated to levels required for electric resistance (ER) heating.

(2) Includes roof/ceiling assemblies, in which the finished ceiling is the underside of the roof deck.

(3) For floors of heated spaces over unheated basements, unheated garages or unheated crawl spaces.

TABLE 4. RESIDENCE INSULATION RESISTANCE/U-VALUE DESCRIPTION

WINTER DEGREE DAYS	EXTERIOR WALL		ROOF	
65° BASE	INSUL RESIS	TOTAL U-VALUE	INSUL RESIS	TOTAL U-VALUE
0 - 1000	10.26	.08	16.44	.05
1001 - 2500	10.26	.08	16.44	.05
2501 - 3500	10.26	.08	21.44	.04
3501 - 4500	10.26	.08	29.78	.03
4501 - 6000	12.046	.07	29.78	.03
6001 - 7000	12.046	.07	29.78	.03
7001 +	17.76	.05	34.91	.026

WINTER DEGREE DAYS	FLOORS		
65° BASE	INSUL RESIS FLOOR 1	INSUL RESIS FLOOR 2	TOTAL U-VALUE
0 - 1000	9.209	9.696	.07
1001 - 2500	9.209	9.696	.07
2501 - 3500	9.209	9.696	.07
3501 - 4500	9.209	9.696	.07
4501 - 6000	9.209	9.696	.07
6001 - 7000	9.209	9.696	.07
7001 +	14.920	15.410	.05

TABLE 5. SURFACE LAYER DESCRIPTIONS

SURFACE	MATERIAL	THICKNESS (ft)	CONDUCTIVITY (Btu/hr-ft-°F)	DENSITY (lbs/ft^3)	SPECIFIC HEAT (Btu/lb-°F)
Exterior Wall	Outside Film Resistance = Varies with wind speed				
	Exterior Finish	.0625	.4167	166	.2
	3/8" Plywood	.0313	.0667	34	.29
	Insulation Resistance = Varies with climate				
	1/2" Gypsum Wall Board	.0417	.0926	50	.2
	Inside Film Resistance = .69				
Roof	Outside Film Resistance = Varies with wind speed				
	Asphalt Roll Resistance = .15				
	5/8" Plywood Sheathing	.0521	.0667	34	.29
	Insulation Resistance = Varies with climate				
	Ceiling Air Resistance = .92				
	1/2" Gypsum Wall Board	.0417	.0926	50	.2
	Inside Film Resistance = .765 (Average of heat flow up/down)				
Floor 1 with Crawl Space	Outside Film Resistance = .765 (Average of heat flow up/down)				
	Insulation Resistance = Varies with climate				
	5/8" Plywood subfloor	.0521	.0667	34	.29
	3/4" Hardwood	.0628	.0916	45	.3
	Carpet Resistance = 2.08				
	Inside Film Resistance = .765 (Average of heat flow up/down)				
Floor 2 Slab on Ground	Outside Film Resistance = .765 (Average of heat flow up/down)				
	1 1/4" LW Concrete	.1042	.2083	80	.2
	Insulation Resistance = Varies with climate				
	6" HW Concrete	.5	1.0417	140	.2
	Carpet Resistance = 2.08				
	Inside Film Resistance = .765 (Average of heat flow up/down)				
Interior Walls	Outside Film Resistance = .68				
	2 3/8" Gypsum Wall Board + Air Resistance = 1.676				
	Inside Film Resistance = .68				
Windows	Outside Film Resistance = Varies with wind speed				
	Air Space Resistance = .9				
	Inside Film Resistance = .5				
Furniture	Outside Film Resistance = .68				
	Furniture =	.166	.09	34	.6
	Inside Film Resistance = .68				
Crawl Space Wall	Outside Film Resistance = Varies with wind speed				
	8" HW Concrete =	.6667	.7576	140	.2
	Inside Film Resistance = .68				

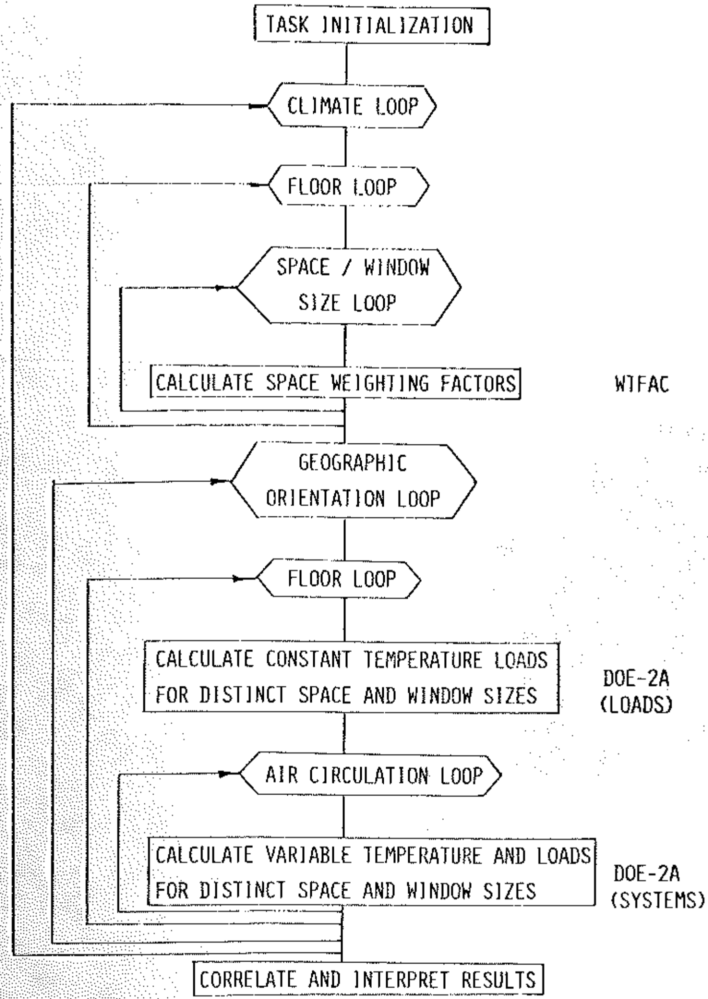


Fig. 1. Methodology Flow Diagram

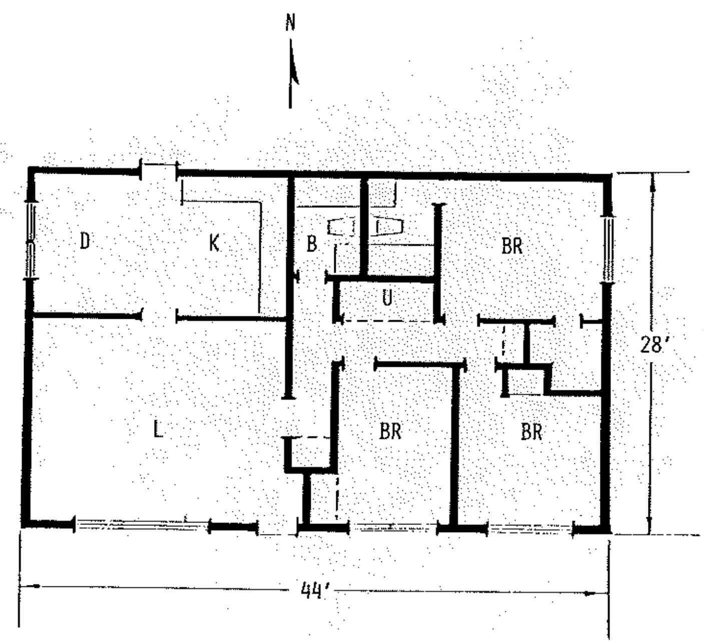


Fig. 2. Residence Floor Plan

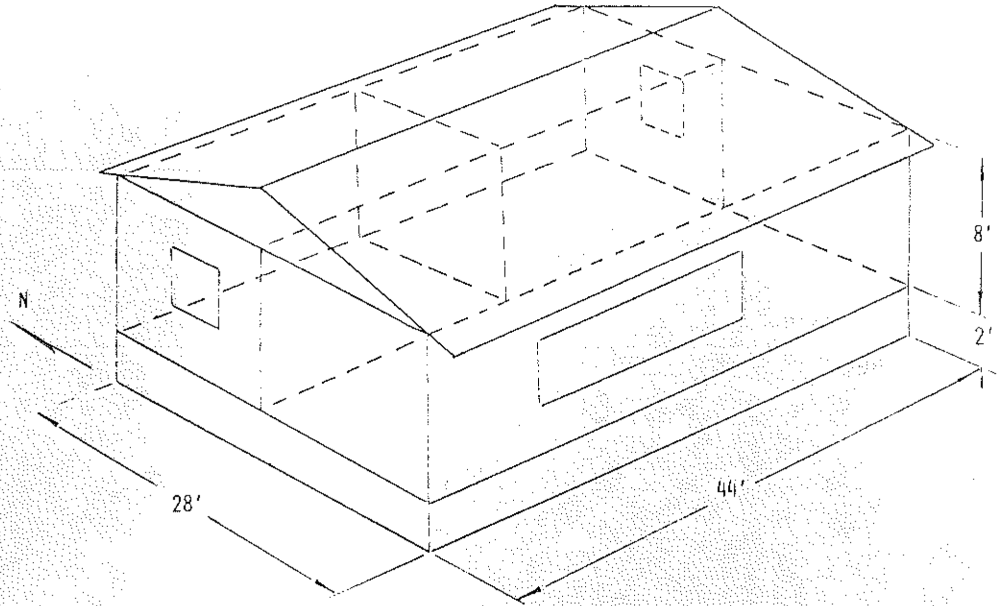
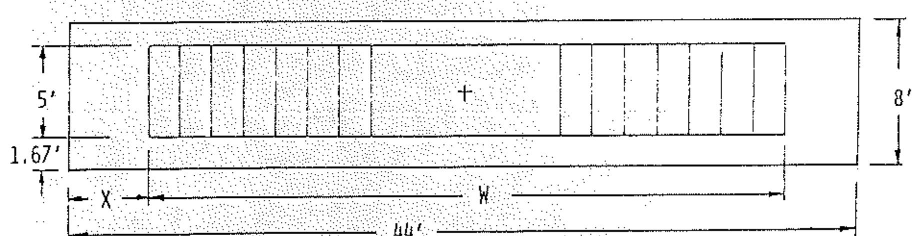


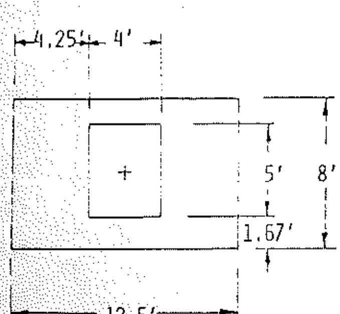
Fig. 3.
Residence Zone Description

Fig. 4.
Window Size Variations for Living/South Bedroom Zone

NUMBER	% A_{FLOOR}	% A_{WALL}	A_{WINDOW} (FT^2 - GROSS)	W (FT)	X (FT)
1	7.7	15	52.8	10.56	16.72
2	10.3	20	70.4	14.08	14.96
3	12.9	25	88.0	17.60	13.20
4	15.5	30	105.6	21.12	11.44
5	18.1	35	123.3	24.64	9.68
6	20.6	40	140.8	28.16	7.92
7	23.2	45	158.4	31.68	6.16
8	25.8	50	176.0	35.20	4.40



KITCHEN / DINING ZONE

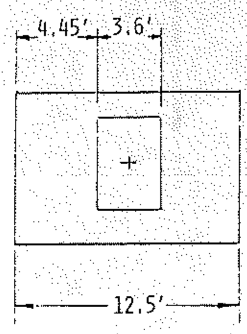


A_{WINDOW} = 20 FT^2 (GROSS)

% A_{FLOOR} = 8

% A_{WALL} = 20

NORTH BEDROOM ZONE



A_{WINDOW} = 18 FT^2 (GROSS)

% A_{FLOOR} = 6

% A_{WALL} = 18

Fig. 5.
Window Sizes for Kitchen/ Dining and North Bedroom Zones

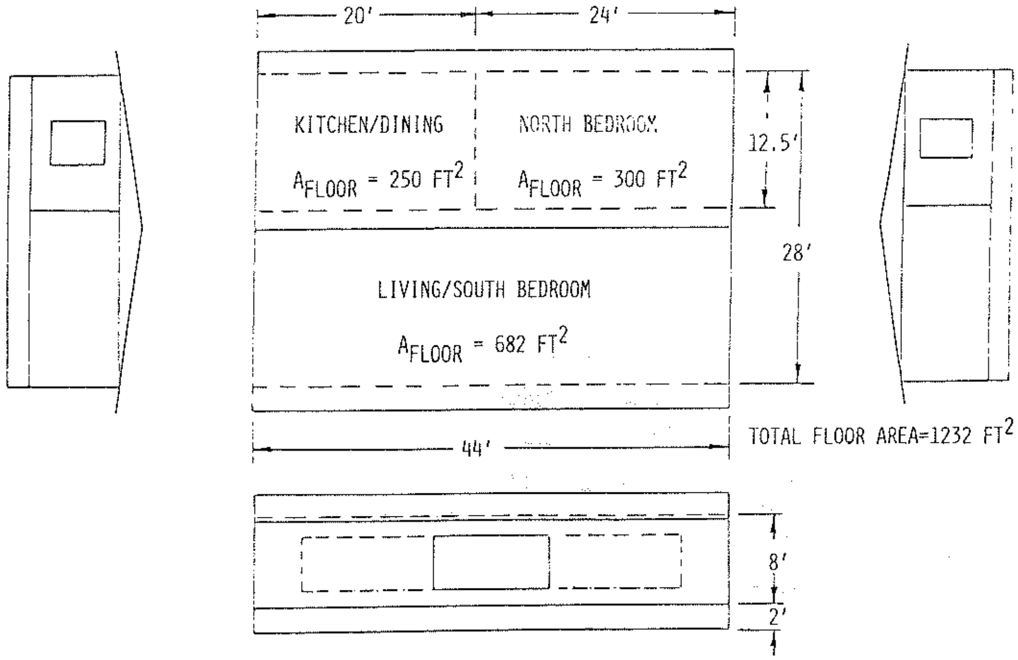


Fig. 6. Residence Floor Plan/Zone Description

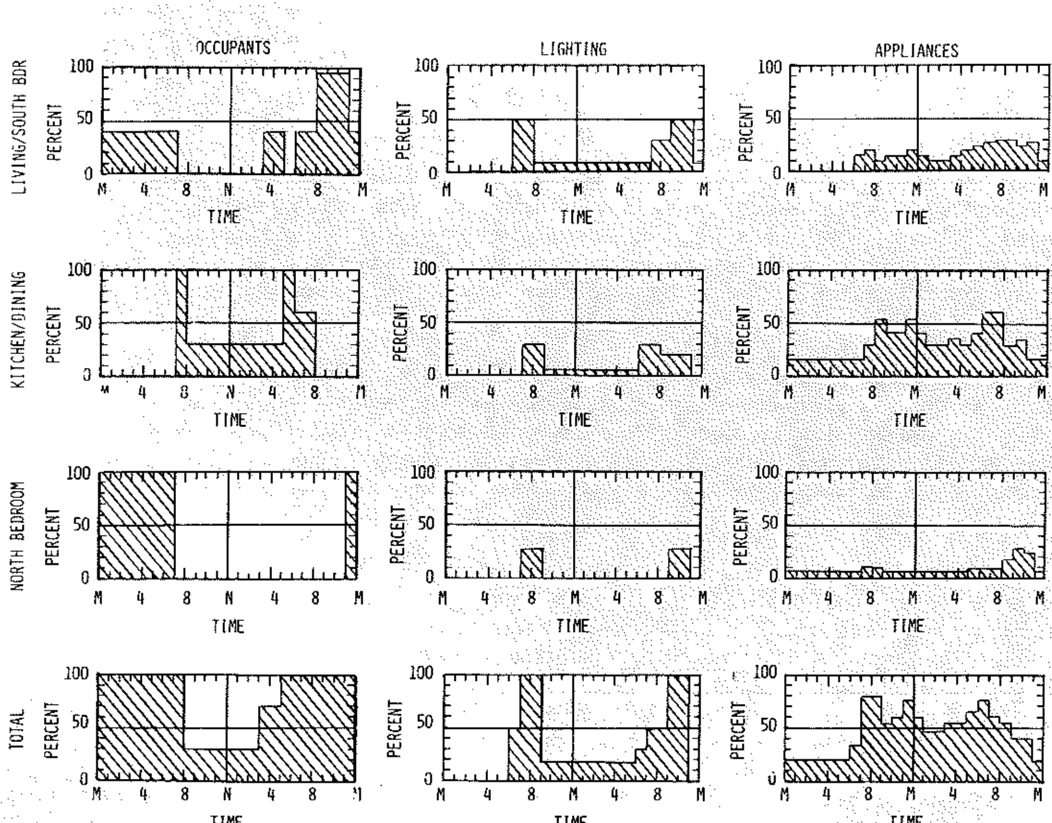


Fig. 7. Scheduling Information