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ADDITIONAL COOLING AND HEATING
LOAD IMPROVEMENTS IN
SEASONAL PERFORMANCE MODELING
OF ROOM AND CENTRAL AIR CONDITIONERS
AND HEAT PUMPS

MASTER

Topical Report - Subtask 3.2

9 April 1980

Prepared for

The Assistant Secretary for Conservation
and Solar Applications
U. S. Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585

Under Contract No.

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9 April 1980

U. S. Department of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585

Attention: Mr. Richard Dudley, Program Manager

Subject: Topical Report-Subtask 3.2, Contract DE-AC03-79-CS10757

Dear Mr. Dudley:

In accordance with the requirements of the subject contract, enclosed are four copies of Topical Report-Subtask 3.2 for Contract DE-AC03-79-CS10757 entitled "Additional Cooling and Heating Load Improvements in Seasonal Performance Modeling of Room and Central Air Conditioners and Heat Pumps," SAI-444-80-311-LJ.

If you have any questions or comments, please contact me at (714) 454-3811, Extension 2561.

Sincerely,

Mort Blatt

Morton H. Blatt
Program Manager

MHB:evm
Enclosures

cc: DOE/SAN, Attn: Conservation Division

TABLE OF CONTENTS

1.	SUMMARY	1-1
2.	INTRODUCTION	2-1
3.	SPM COOLING AND HEATING LOAD MODELS	3-1
4.	COMPUTER SIMULATION PROGRAM METHODOLOGY (SPMLD)	4-1
5.	RESULTS	5-1
	5.1 Cooling	5-1
	5.2 Heating	5-53
6.	CONCLUSION	6-1
7.	REFERENCES	7-1
	APPENDIX A - Manual J. Analysis for Cooling and Heating Loads Calculation	A-1
	APPENDIX B - Comparison of Cooling Loads of SPMLD and Improved SPM at 80°F Indoor Dry- Bulb Temperature	B-1

LIST OF TABLES

S-1	Percentage Difference of Total Cooling Load of SPM and Improved SPM Relative to SPMLD for Three Different Climatic Regions With Indoor Temperature of 75°F Averaged Over Day and Night Intervals	1-4
S-2	Percentage Difference of Total Cooling Load of SPM and Improved SPM Relative to SPMLD for Three Different Climatic Regions With Indoor Temperature of 70°F	1-6
1.	Summary of Advantages and Disadvantages of Existing Computer Simulation Methods	2-2
2.	Physical Data of a Residence for Load Calculation	2-4
3.	Heat Transfer Coefficients of Building Components	2-5
4.	Meteorological Characteristics of Climates Used for Comparison Between SPM Load Model and SPMLD Results	2-6
5.	Cooling SPM Treatment of Load Components	3-2
6.	SPM Design Cooling Load Calculation for Example Residence in Columbia, Missouri for Solar-Hours	3-4
7.	SPMLD Non-Weather Related Input Variables	4-3
8.	Average Value of Relative Humidity in Each Relative Humidity Bin for Cooling and Heating in Three Climates Studied Based on 8-hr "Solar Hours" Interval	4-5
9.	Percentage Difference of Total Cooling Load of SPM and Improved SPM Relative to SPMLD for Three Different Climatic Regions With Indoor Temperature of 75°F Averaged Over Day and Night Intervals	5-54
10.	Percentage Difference of Total Heating Load of SPM and Improved SPM Relative to SPMLD for Three Different Climatic Regions With Indoor Temperature of 70°F	5-69

LIST OF FIGURES

1-1	Comparison of the Infiltration Rate of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 75°F in Cooling Season in Columbia, Missouri	
	a) The 8-hour Daytime Interval	5-2
	b) The 16-hour Nighttime Interval	5-3
1-2	Comparison of the Infiltration Rate of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 75°F in Cooling Season in Ft. Worth, Texas	
	a) The 8-hour Daytime Interval	5-4
	b) The 16-hour Nighttime Interval	5-5
1-3	Comparison of the Infiltration Rate of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 75°F in Cooling Season in Caribou, Maine	
	a) The 8-hour Daytime Interval	5-6
	b) The 16-hour Nighttime Interval	5-7
2-1	Comparison of the Latent Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Columbia, Missouri	
	a) The 8-hour Daytime Interval	5-9
	b) The 16-hour Nighttime Interval	5-10
2-2	Comparison of the Latent Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas	
	a) The 8-hour Daytime Interval	5-11
	b) The 16-hour Nighttime Interval	5-12
2-3	Comparison of the Latent Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Caribou, Maine	
	a) The 8-hour Daytime Interval	5-13
	b) The 16-hour Nighttime Interval	5-14
3-1	Comparison of the Sensible Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Columbia, Missouri	
	a) The 8-hour Daytime Interval	3-15
	b) The 16-hour Nighttime Interval	5-16

LIST OF FIGURES (Cont'd)

3-2	Comparison of the Sensible Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas	
	a) The 8-hour Daytime Interval	5-17
	b) The 16-hour Nighttime Interval	5-18
3-3.	Comparison of the Sensible Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Caribou, Maine	
	a) The 8-hour Daytime Interval	5-19
	b) The 16-hour Nighttime Interval	5-20
4-1	Comparison of the Solar Window Heat Gain of SPMLD, SPM and Improved SPM Treatments in Columbia, Missouri	
	a) The 8-hour Daytime Interval	5-21
	b) The 16-hour Nighttime Interval	5-22
4-2	Comparison of the Solar Window Heat Gain of SPMLD SPM and Improved SPM Treatments in Ft. Worth, Texas	
	a) The 8-hour Daytime Interval	5-23
	b) The 16-hour Nighttime Interval	5-24
4-3	Comparison of the Solar Window Heat Gain of SPMLD, SPM and Improved SPM Treatments in Caribou, Maine	
	a) The 8-hour Daytime Interval	5-25
	b) The 16-hour Nighttime Interval	5-26
5-1.	Comparison of the Summation of Wall, Door, and Floor Heat Gain of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 75°F in Columbia, Missouri	
	a) The 8-hour Daytime Interval	5-28
	b) The 16-hour Nighttime Interval	5-29
5-2	Comparison of the Summation of Wall, Door, and Floor Heat Gain of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas	
	a) The 8-hour Daytime Interval	5-30
	b) The 16-hour Nighttime Interval	5-31
5-3	Comparison of the Summation of Wall, Door, and Floor Heat Gain of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 75°F in Caribou, Maine	
	a) The 8-hour Daytime Interval	5-32
	b) The 16-hour Nighttime Interval	5-33

LIST OF FIGURES (Cont'd)

6-1	Comparison of the Window Conduction Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Columbia, Missouri	
	a) The 8-hour Daytime Interval	5-34
	b) The 16-hour Nighttime Interval	5-35
6-2	Comparison of the Window Conduction Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas	
	a) The 8-hour Daytime Interval	5-36
	b) The 16-hour Nighttime Interval	5-37
6-3	Comparison of the Window Conduction Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Caribou, Maine	
	a) The 8-hour Daytime Interval	5-38
	b) The 16-hour Nighttime Interval	5-39
7-1	Comparison of the Ceiling Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Columbia, Missouri	
	a) The 8-hour Daytime Interval	5-40
	b) The 16-hour Nighttime Interval	5-41
7-2	Comparison of the Ceiling Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas	
	a) The 8-hour Daytime Interval	5-42
	b) The 16-hour Nighttime Interval	5-43
7-3	Comparison of the Ceiling Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Caribou, Maine	
	a) The 8-hour Daytime Interval	5-44
	b) The 16-hour Nighttime Interval	5-45
8-1	Comparison of the Total Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Columbia, Missouri	
	a) The 8-hour Daytime Interval	5-45
	b) The 16-hour Nighttime Interval	5-46
8-2	Comparison of the Total Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas	
	a) The 8-hour Daytime Interval	5-48
	b) The 16-hour Nighttime Interval	5-49

LIST OF FIGURES (Cont'd)

8-3	Comparison of the Total Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Caribou, Maine	
	a) The 8-hour Daytime Interval	5-50
	b) The 16-hour Nighttime Interval	5-51
9-1	Comparison of the Infiltration Rate of SPMLD Averaged Over 24-Hour Interval and the Infiltration Rate Model at an Indoor Temperature of 70°F in Heating Season in Columbia, Missouri	5-55
9-2	Comparison of the Infiltration Rate of SPMLD Averaged Over 24-Hour Interval and the Infiltration Rate Model at an Indoor Temperature of 70°F in Heating Season in Ft. Worth, Texas	5-56
9-3	Comparison of the Infiltration Rate of SPMLD Averaged Over 24-Hour Interval and the Infiltration Rate Model at an Indoor Temperature of 70°F in Heating Season in Caribou, Maine	5-57
10-1	Comparison of the Sensible Infiltration Heat Loss of SPMLD Averaged Over 24-Hour Interval and the Load Based on Infiltration Model at an Indoor Temperature of 70°F in Columbia, Missouri	5-59
10-2	Comparison of the Sensible Infiltration Heat Loss of SPMLD Averaged Over 24-Hour Interval and the Load Based on Infiltration Model at an Indoor Temperature of 70°F in Ft. Worth, Texas	5-60
10-3	Comparison of the Sensible Infiltration Heat Loss of SPMLD Averaged Over 24-Hour Interval and the Load Based on Infiltration Model at an Indoor Temperature of 70°F in Caribou, Maine	5-61
11-1	Comparison of the Total Heat Loss Minus Heat Loss Due to Infiltration of SPMLD Averaged Over 24-Hour Interval and Improved SPM at an Indoor Temperature of 70°F in Columbia, Missouri	5-62
11-2	Comparison of the Total Heat Loss Minus Heat Loss Due to Infiltration of SPMLD Averaged Over 24-Hour Interval and Improved SPM at an Indoor Temperature of 70°F in Ft. Worth, Texas	5-63

LIST OF FIGURES (Cont'd)

11-3	Comparison of the Total Heat Loss Minus Heat Loss Due to Infiltration of SPMLD Averaged Over 24-Hour Interval and Improved SPM at an Indoor Temperature of 70°F in Caribou, Maine	5-64
12-1	Comparison of the Total Heat Loss of SPMLD Averaged Over 24-Hour Interval, SPM and Improved SPM at an Indoor Temperature of 70°F in Columbia, Missouri	5-66
12-2	Comparison of the Total Heat Loss of SPMLD Averaged Over 24-Hour Interval, SPM and Improved SPM at an Indoor Temperature of 70°F in Ft. Worth, Texas	5-67
12-3	Comparison of the Total Heat Loss of SPMLD Averaged Over 24-Hour Interval, SPM and Improved SPM at an Indoor Temperature of 70°F in Caribou, Maine	5-68

1. SUMMARY

This study is a continuation of work (Reference 1), which focussed on improving the load modeling technique of the Seasonal Performance Model (SPM). Although earlier studies utilized weather data for Kansas City during the year 1960 to calculate the cooling and heating loads of a specified building, this report uses typical weather data for three different climates.

SAI has previously developed a Cooling Seasonal Performance Model (Cooling SPM) and a Heat Pump Heating Seasonal Performance Model (Heating SPM) for the DOE (Reference 2). Both models employed Manual J analysis, which is the most commonly utilized method for load modeling. The objective of this study is to improve the load modeling technique of SPM in order to estimate a more realistic load for seasonal analysis calculations.

A computer simulation program, entitled Seasonal Performance Model Load (SPMLD) was used to calculate the cooling and heating loads on an hourly basis. SPMLD has been used to analyze the cooling and heating loads for a typical residence in the following climatic regions:

- o Caribou, Maine
- o Columbia, Missouri
- o Fort Worth, Texas

SPMLD reads NOAA hourly weather tapes, calculates the cooling and heating loads by hour, aggregates the data, and plots graphs of the results. The SPMLD cooling load results indicate that the following major improvements have significantly reduced

the deviation of cooling SPM load predictions from cooling SPMLD predictions.

- o Infiltration levels are not constant as was assumed in the cooling SPM, but depend on the difference between outdoor and indoor dry-bulb temperatures; and
- o Solar loads are correlated with outdoor relative humidity and temperature and vary significantly in contrast to the cooling SPM algorithm which assumed constant solar loads.

Two ratios were defined in order to estimate the amount that the SPM and Improved SPM deviate from the SPMLD results. (Improved SPM is the revised SPM load model based on infiltration and solar load algorithms). The first ratio is:

$$ERR1 = \frac{\sum_T \sum_{RH} f(RH, T) [Q(SPMLD) - Q(IMP. SPM)] \times 100}{\sum_T \sum_{RH} f(RH, T) Q(SPMLD)}$$

where

$Q(SPMLD)$ = Cooling or heating loads calculated by SPMLD at each specific relative humidity and temperature bin.

$f(RH, T)$ = Frequency of number of hours in the cooling or heating season in the specified relative humidity and temperature bin.

$Q(IMP.SPM)$ = Cooling or heating loads calculated by Improved SPM at each specific relative humidity and temperature bin.

The denominator of this equation represents the total cooling or heating load during the cooling or heating season calculated by the SPMLD technique, while the numerator represents the difference between the cooling or heating load values, each calculated by a separate technique (SPMLD or Improved SPM). The

ratio (ERR1) represents the percentage difference of cooling or heating load for the whole cooling or heating season. Physically, this ratio estimates the variation in a building's energy consumption during a cooling or heating season, if the building load calculation is performed by the Improved SPM technique rather than an hourly computer simulation technique such as SPMLD.

The second ratio (ERR2), the percentage load difference between the two methods averaged over all relative humidity and temperature bins determines how close is the agreement between the Improved SPM load model and the SPMLD when they are plotted as functions of outdoor dry-bulb temperature bins with relative humidity bin as a parameter. This ratio is defined as:

$$ERR2 = \sum_T \sum_{RH} f(RH, T) \left[1 - \frac{Q(IMP. SPM)}{Q(SPMLD)} \right] * \frac{Q(SPMLD)}{QMJ} \times 100$$

where QMJ is the Manual J cooling or heating load. This ratio has a weighting factor of $Q(SPMLD)/QMJ$ to reflect the large differences between SPMLD and Improved SPM at high cooling or heating load points. (The high load points are points where $Q(SPMLD)$ is near QMJ).

These two ratios have been calculated for three different climatic regions. Table S-1 presents these ratios for cooling load calculations, in which the SPM and Improved SPM have been compared with SPMLD. This table is based on an eight hour "Solar Hours" interval and 75°F indoor temperature. The numbers in this table are the average of "Solar-Hours" and "Dark Hours". As shown, the deviations from SPMLD have decreased considerably due to improvements in the cooling SPM load model, especially in the climatic regions with higher cooling loads.

Table S-1. Percentage Difference of Total Cooling Load of SPM and Improved SPM Relative to SPMLD for Three Different Climatic Regions With Indoor Temperature of 75°F Averaged Over Day and Night Intervals

	ERR1		ERR2	
Location	SPM	Improved SPM	SPM	Improved SPM
Caribou, ME	14.8	-4.3	63	-15.7
Columbia, MO	10.1	- .9	29.4	- 5
Ft. Worth, TX	10.8	-1.6	23.3	- 9.4

The SPMLD heating load analysis indicates that the following improvements will reduce the amount that the heating SPM load prediction deviates from the heating SPMLD load prediction.

- o The infiltration level depends on the difference between the outdoor and indoor dry-bulb temperatures according to a specified algorithm.
- o Total heat loss minus infiltration loss is modeled at 65% of the Manual J heating value at the design condition and zero at 60°F with linear interpolation and extrapolation at other outdoor temperatures.

Table S-2 shows the two ratios calculated for heating load in the heating season for three different climatic regions. The table is based on an indoor dry-bulb temperature of 70°F. According to this table, the deviations from SPMLD have decreased due to improvements in the Heating SPM load modeling, especially in the climatic regions with higher heating loads.

Table S-2. Percentage Difference of Total Heating Load of SPM and Improved SPM Relative to SPMLD for Three Different Climatic Regions With Indoor Temperature of 70°F

	ERR1		ERR2	
Location	SPM	Improved SPM	SPM	Improved SPM
Caribou, ME	5	2	9	4
Columbia, MO	-3	-2	-7	-5
Ft. Worth, TX	-10	-6	-28	-17

2.0 INTRODUCTION

This study is a continuation of the previous report (Reference 1), which focussed on improving the load modeling technique of Seasonal Performance Model (SPM). In earlier work, weather data for Kansas City during the year 1960 was used to calculate the cooling and heating loads of a specified building while this report uses typical weather data for three different climates.

The Cooling Seasonal Performance Model (Cooling SPM) and Heat Pump Heating Seasonal Performance Model (HP Heating SPM), developed for DOE by Science Applications, Inc. (Reference 2), utilize Manual J analysis (Reference 3) which is the most common method for load modeling. In this method, the heating side is based on the difference between indoor and outdoor temperatures, whereas the cooling side is based on outdoor temperature and a daily temperature range (low, medium or high). An example of Manual J analysis is discussed in Appendix A.

The objective of this work is to improve the load modeling technique of the SPM in order to estimate a more realistic load for seasonal analysis calculations. In this regard, a computer simulation program was used to calculate the cooling and heating loads on an hourly basis.

Many computer simulation methods are available in the open literature and in the private domain, to analyze the energy consumption of buildings. The advantages and disadvantages of each program are presented in Table 1.

In order to shorten the computational labor and the cost common to most hourly simulation computer programs NBS has developed, a simplified energy calculation procedure called HEAP (Home Energy Audit Program). The results of the calculations

Table 1. Summary of Advantages and Disadvantages of Existing Computer Simulation Methods

Program Name	Advantage	Disadvantage	Developer
DOE-2 ≈ CEC-1	Detailed, accurate information	Commercial building only*	DOE
BLAST-2	High level of technical sophistication for load calculation, simple input language	Absence of simulation capability for HVAC systems, lack of extensive verification effort	U.S. Army Construction Engineering Research Lab
NBSLD	Validated on several experimental buildings	Computer cost and complexity of the input	NBS
HEAP	Ease of use and low cost of computer time	Lack of technical sophistication when compared to DOE-2 or BLAST	NBS
Two-Zone	Low cost and ability to assess natural cooling	Limited scope relative to thermal load and HVAC system types	LBL

*The residential capability is currently being incorporated at Lawrence Berkeley Laboratory (LBL)

obtained by this simplified routine have been compared against those obtained from the comprehensive hourly simulation routine, NBSLD, with respect to a ranch house.

SAI studied HEAP in great detail. During this investigation many of the algorithms in the program were reconstructed and the whole procedure was given a new name, SABLE (Science Applications Building Load Estimator). SABLE includes the following major features, in addition to HEAP:

- o A central air conditioner performance model
- o The ability to use random billing periods
- o An algorithm to handle the more detailed weather data in a simplified manner.

SAI verified SABLE against the BLAST computer program, which is a more detailed model, using two house types. Each house was analyzed for one year of weather data for two climates. The results demonstrated the relative accuracy that was expected. Although the BLAST program was never validated against a physical system to establish a level of confidence, the fundamental concepts include models of components that are linked by a suitable mathematical framework which presumably replicates accepted practices and experiences. In addition, SAI performed a sensitivity analysis and compared SABLE's predictions with those of BLAST.

SABLE was modified to handle hourly weather data from the Typical Meteorological Year (TMY) weather tapes. The improved program is entitled SPMLD (Seasonal Performance Model Load) and will be briefly discussed in the following section.

The SPM load model and SPMLD results have been compared using a residence with building characteristics shown in Table 2.

Table 2. Physical Data of a Residence for Load Calculation

PARAMETERS	
Volume	12,832 ft ³
Floor Area/Story	778 ft ²
Window Area	130 ft ²
Wall Area	1,303 ft ²
Door Area	40 ft ²
Exposed Perimeter	110 ft
Window Shading Coefficient	.55
Window Shadow Factor	0
Wall and Door Surface Absorptivity	.4
Wall and Door Shadow Factor (Except west side, which is 0.5)	0
Roof Absorptivity	.9
Roof Shadow Factor	0

The residence is a two story building with slab-on-grade floor, no basement and an attic which is not temperature controlled. The heat transfer coefficients of the building components shown in Table 3 are input variables for the SPMLD program. The SPM load model and SPMLD results have been compared for three different climates with meteorological characteristics shown in Table 4.

The locations were selected to insure a wide range of heating and cooling degree-days. In this way, extreme climates such as Caribou, Maine for heating and Fort Worth, Texas for cooling, were studied, as well as an average U.S. climate (Columbia, Missouri).

Table 3. Heat Transfer Coefficients of Building Components

COMPONENT	Btu/hr °F ft ²
Wall (R-11 insulation)	0.09
Pitched Roof	.5
Ceiling (R-19 insulation)	0.05
Double Glass Window	.6
Storm Door	.5
Attic End Wall	.25
Floor (no edge insulation)	.121

Table 4. Meteorological Characteristics of Climates Used for Comparison Between SPM Load Model and SPMLD Results

	Caribou, Maine	Columbia, Missouri	Ft. Worth, Texas
Summer Outdoor Design Temperature (°F)	80	95	100
Winter Outdoor Design Temperature (°F)	-15	5	20
Daily Temperature Range	Medium	Medium	Medium
Heating Degree Days (Based on 65°F)	9632	5083	2382
Cooling Degree Days (Based on 65°F)	128	1269	2587
Latitude (Degrees North)	47	40	33
Longitude (Degrees West)	68	95	97
Outdoor Dry-Bulb Temperature	NOAA Weather Tape	NOAA Weather Tape	NOAA Weather Tape
Outdoor Relative Humidity			
Wind Speed			
Cloud Type			
Cloud Cover			
Average Ground Temperature (°F)			
Cooling Season	42	66	70
Heating Season	32	46.5	62

In the SPM cooling load model (Reference 2), the cooling load at the design conditions is calculated by Manual J analysis, which is described in Appendix A. Cooling load calculations at other conditions (other outdoor temperatures or indoor temperatures) in the SPM cooling load model are summarized in Table 5. A cooling day is divided into "Solar-Hours" and "Dark-Hours". The "Solar-Hours" segment is usually eight hours long, from 10 a.m. through 5 p.m., and the remainder of the day is considered to be the "Dark-Hours" portion.

The sensible transmitted operating load, represented by " q_t^{oi} ", is composed of several load components. The design load (DL) for each component is calculated by the Manual J method. The solar load through windows in "Solar-Hours" is equal to the solar component of fenestration, which is calculated in Manual J and is assumed to be zero at the "Dark Hours".

The internally generated sensible load, represented by " q_s^{ii} ", is assumed to be temperature-independent. SPM treatment assumes different sensible loads for people and appliances than Manual J calculation (Appendix A), which estimates 300 Btu/hr for each person and a total of 1200 Btu/hr for appliances.

The internally generated latent load, represented by " q_l^{ii} ", is based on an average of 1 person per 500 ft². This treatment is also different from the Manual J calculation, which assumes 30% of total sensible load as latent load.

The infiltration load is treated by the air change method in the SPM, with an assumed constant air changeover rate of .5 per hour for cooling load calculations for all weather conditions. Again, this treatment is different from the Manual J calculation, in which the sensible infiltration load is part of

Table 5. Cooling SPM Treatment of Load Components

SPM FACTOR	COMPONENT	ENTRY BY TIME OF DAY SPECIFIED	
		SOLAR-HOURS	DARK-HOURS
q_t^{oi}	FENESTRATION:		
	SOLAR	DL	θ
	AIR/AIR	$\frac{\Delta T_a - 4}{\Delta T_d - 4} \cdot DL$	$\frac{\Delta T_a}{\Delta T_d - 4} \cdot DL$
	WALLS AND DOORS:		
	CONDUCTION	$\frac{\Delta T_a + X}{\Delta T_d + X} \cdot DL$	$\frac{\Delta T_a}{\Delta T_d + X} \cdot DL$
	CEILING	$\frac{\Delta T_a + Y}{\Delta T_d + Y} \cdot DL$	$\frac{\Delta T_a}{\Delta T_d + Y} \cdot DL$
q_s^{ii}	PEOPLE	250 Btu/hr per 4000 ft ³	
	APPLIANCES	250 Btu/hr per 4000 ft ³	
q_ℓ^{ii}	PEOPLE	220 Btu/hr per 4000 ft ³	
	OTHER	55 Btu/hr per 4000 ft ³	
$q_{ins}^{oi}, q_{inl}^{oi}$	INFILTRATION		
	<p>N = No. of Air Change/hr</p> <p>V = Residence Volume</p>	$q_{ins}^i = 1.08 \frac{NV}{60} \times \Delta T_a$ $q_{inl}^i = \frac{NV}{60} (W_0 - W_I) \times 0.075 \times 1060$	

NOTES: DL $\equiv$ DESIGN LOAD $\Delta T_a \equiv$ ACTUAL TOD-TIN $\Delta T_d \equiv$ DESIGN TOD-TIN $W_0 \equiv$ OUTDOOR RH $W_I \equiv$ INDOOR RHX: -1.4 for H, 3.6 for M,
and 7.6 for LY: 15 for H, 20 for M,
and 24 for L

the wall and door load and the latent infiltration load is part of 30% of the total sensible load.

Table 6 shows SPM design cooling load calculations for "Solar-Hours" for the sample residence in Columbia, Missouri. In this table, the sensible load due to infiltration is equal to:

$$q_{ins}^i = \frac{1.08 \times N \times V}{60} \times \Delta T_d = \frac{1.08 \times 0.5 \times V}{60} (95-75) = 0.18V \quad (1)$$

The latent load due to infiltration is (outdoor relative humidity of 40% and indoor relative humidity of 50%.):

$$\begin{aligned} q_{inl}^i &= (W_O - W_I) \frac{N \times V}{60} \times 0.075 \times 1060 \\ &= [0.0142 - 0.0092] \times \frac{0.5 \times V}{60} \times 0.075 \times 1060 = .199V \end{aligned} \quad (2)$$

The total cooling load will be 17,820 Btu/hr, as compared to 19,740 Btu/hr by the Manual J procedure (Appendix A).

In the SPM heating load model, the heating load at the design condition is calculated on the basis of the Manual J analysis, which is 29540 Btu/hr for the sample residence in Columbia, Missouri (Appendix A). Heating loads at other outdoor temperatures in SPM treatment are modeled as a straight line connecting the heating load at the design condition with a zero load at 65°F outdoor temperature, assuming an indoor temperature of 70°F. For other indoor temperatures, the heating load line is simply raised or lowered to reflect the temperature differential at each outdoor dry-bulb temperature. The linear nature of the load line is maintained.

Table 6. SPM Design Cooling Load Calculation for Example Residence in Columbia, Missouri for Solar-Hours

PARAMETERS	VALUE
Design Temperatures & Relative Humidity	
Outdoor Dry Bulb Temperature	95°F
Indoor Dry Bulb Temperature	75°F
Outdoor Relative Humidity	40%
Indoor Relative Humidity	50%
Daily Temperature Range	M
Fenestration:	
Solar	5,590 Btu/hr
Air/Air	910 Btu/hr
Walls and Doors	
Conduction	2,415
Ceiling	1,556
People (250 Btu/hr per 4000 ft ³)	802
Appliances (250 Btu/hr per 4000 ft ³)	802
Infiltration (.18V)	2,309
Total Sensible Gain	14,384
Latent Gain	
People (220 Btu/hr per 4000 ft ³)	706
Other (55 Btu/hr per 4000 ft ³)	176
Infiltration (0.199V)	<u>2,554</u>
Total Gain	17,820

The Seasonal Performance Model Load (SPMLD) program was derived from the National Bureau of Standards (NBS) Home Energy Audit Program (HEAP). HEAP is based largely on ASHRAE algorithms for calculating component load values. These values are used in HEAP to obtain average heating and cooling loads for a season.

SPMLD retains many of the same ASHRAE algorithms, but is designed to operate on an hourly basis and thereby calculates hourly values of component loads as a function of the following weather variables:

- o outdoor dry-bulb temperature
- o outdoor relative humidity
- o wind speed
- o cloud cover, and
- o cloud type.

The SPMLD program was expanded with respect to weather data to handle the above variables utilized in the simulation. The weather data is read by a separate computer code which compresses a year's worth of hourly observations into a small data file containing the date, time of observation, dry-bulb temperature, relative humidity, wind speed, total cloud amount and cloud type. Two computer codes are capable of producing this compressed weather data file from either TDF 1440 weather tapes or Typical Meteorological Year (TMY) weather tapes, both of which are currently available for many U.S. locations from the National Oceanic and Atmospheric Administration (NOAA) in Asheville, North Carolina (Reference 4). The compressed weather data file is directly input into the SPMLD code. At present twenty-eight different locations on TMY weather tape are available to the SPMLD program.

In addition, the SPMLD requires the inputs listed in Table 7. Each of four window/wall/door surfaces are treated separately, and attics, basements, crawl spaces, and internal load sources are included. Heat storage effects are not included in the SPMLD, and therefore, all heat gains and losses are the steady state values that would be obtained, if the weather and internal conditions were to persist indefinitely. This treatment could also be applied in transient situations for light structures, such as wooden frame buildings, where thermal storage effects are negligible.

The infiltration rate in SPMLD for cooling and heating load estimates is a function of outdoor temperature and wind speed, as follows:

$$N(T_{db}^O, WSD) = \frac{N(STD)}{.695} [.15 + 0.013WSD + 0.005ABS(T_{db}^O - T_{db}^i)] \quad (3)$$

where " $N(T_{db}^O, WSD)$ " is the actual infiltration rate (air change/hr), " $N(STD)$ " is the standard infiltration rate (air change/hr) for which a value of one air change/hr has been assumed for this study, " WSD " is the wind speed (mph), " T_{db}^O " and " T_{db}^i " are the outdoor and indoor dry bulb temperatures ($^{\circ}F$) respectively.

The output of SPMLD has been separated into the following components:

- o wall, door and floor conduction
- o ceiling conduction
- o window conduction
- o window solar gain
- o sensible infiltration
- o latent infiltration

Table 7. SPMLD Non-Weather Related Input Variables

General

Latitude and longitude of the site.
 Volume of the residence.
 Standard air leakage rate.
 Ground surface reflectance.
 Ground temperature.
 Surface heat transfer coefficient.
 Indoor dry-bulb temperature.
 Indoor relative humidity.
 Orientation of each of four window/wall/door surfaces.
 Sensible internal load.
 Latent internal load.

Each Wall

Surface absorptivity, U-value, area, and shadow factor.

All the Windows Combined on Each Wall

Area, U-value, shading coefficient, and shadow factor.

Roof

Non-attic roof area, absorptivity, U-value and shadow factor.

Floor

Projected floor area.
 Fractions of floor that are slab-on-grade, crawl space,
 and basement.
 U-value for floor over basement.
 U-value for slab-on-grade.

Attic

End wall height, area, and U-value.
 Air changeover rate.
 Temperature controlled/not-controlled.

Ceiling

U-value.

Basement

Temperature controlled/not-controlled.
 Wall U-value and area.
 Floor U-value.
 Equipment (e.g., furnace) heat gain.

Crawl Space

U-value of floor above crawl space.
 Wall U-value.
 Height and wall area.
 Air changeover rate.

The SPMLD result could be presented for each building component as an average load over the cooling or heating season for that component as a function of outdoor dry bulb temperature with outdoor relative humidity as a parameter. The outdoor temperature is in the form of temperature bin, each 5°F, with the bin temperature equal to the average temperature within the bin. The outdoor relative humidity has been separated into six different bins according to NOAA (Reference 4) and each bin is represented by its average relative humidity for the cooling season.

Table 8 presents the relative humidity bins and the average of relative humidity in each bin over the cooling or heating season for the three climates studied. For cooling, this average is for 8-hour "Solar-Hours" and 16-hour "Dark-Hours". As noted in the table, these averages will vary slightly from one climate to another and therefore one single value for average relative humidity for each relative humidity bin (shown in the last column of Table 8) has been designated independent of the climate.

In order to observe the differences between cooling load estimates of SPMLD and cooling SPM due to building components, equal values of the internal sensible and latent loads for both techniques were input into the models.

Analyses were performed for four cases, as follows:

<u>Indoor Temperature</u>	<u>Solar/Dark Hours</u>
75°F	8 Solar/16 Dark
75°F	12 Solar/12 Dark
80°F	8 Solar/16 Dark
80°F	12 Solar/12 Dark

Table 8. Average Value of Relative Humidity in Each Relative Humidity Bin for Cooling and Heating in Three Climates Studied Based on 8-hr "Solar Hours" Interval (in Percent)

Relative Humidity Bin	CARIBOU, MAINE			COLUMBIA, MISSOURI			FT. WORTH, TEXAS			AVERAGE		
	Cooling		Heating	Cooling		Heating	Cooling		Heating	Cooling		Heating
	Solar	Dark		Solar	Dark		Solar	Dark		Solar	Dark	
RH <30	26	27	28	26	26	23	26	--	24	26	26	25
30 ≤ RH <50	41	43	41	40	43	41	39	43	40	40	43	41
50 ≤ RH <70	58	60	60	58	61	59	58	60	59	58	60	59
70 ≤ RH <80	73	74	74	74	74	74	74	74	74	74	74	74
80 ≤ RH <90	83	84	84	84	84	84	84	84	84	84	84	84
90 ≤ RH ≤ 100	95	95	95	93	93	93	92	92	95	93	93	94

The cooling SPM load model and SPMLD results are very similar for all four cases, although a 12/12 hour segmentation of the day is superior to an 8/16 hour segmentation, particularly for window solar load when there is approximately 12 hours of sunshine. The cooling SPM uses an 8/16 hour segmentation because AFM 88-8 data (Reference 4) are partitioned into three 8-hour groups -- one 10 a.m. to 5 p.m. is used as "Solar-Hours", and the other two (6 p.m. to 1 a.m. and 2 a.m. to 9 a.m.) are combined to form "Dark-Hours". Since AFM 88-8 data are available for a very large number of locations, and no corresponding 12/12 hour data sources have been identified, the 8/16 hour segmentation is retained in the comparison between SPMLD and SPM load models.

The following figures, which discuss the cooling load calculation have two parts, one for an 8-hour daytime interval and the other one for a 16-hour nighttime interval. Figures used to show heating load results are shown only for a 24-hour interval. In these figures, the infiltration rate, load components and total load have been plotted as a function of outdoor dry-bulb temperature for an indoor temperature of 75°F for cooling and 70°F for heating for the three different climatic regions studied. Appendix B presents results obtained for an indoor temperature of 80°F for cooling.

5.0 RESULTS

5.1 COOLING

For the three climates studied, three changes to the SPM cooling load model should be made in order to improve cooling load estimates. They are:

	<u>SPM</u>	<u>Improved SPM</u>
Infiltration rate	Fixed value	Algorithm based on dry-bulb temperature
Solar	100% and 0% values for solar and dark hours respectively	Algorithms based on dry-bulb temperature and relative humidity
Wall Conduction	---	1.4 x (SPM value)

The other load components, as modeled in Table 5, are not changed as a result of the SPMLD analysis, because SPM treatment produced acceptably accurate results.

Figures 1-1, 1-2, and 1-3 compare the infiltration rate of the SPMLD, SPM and Improved SPM for the three different climates studied. The weather data are binned in dry-bulb temperature and relative humidity. Each labeled symbol in these figures represents one group of data, e.g., dry-bulb temperature in the 75-79°F bin and relative humidity in the 30-49% bin. The number of hours in the group are listed next to each symbol. The symbols are plotted at the average value of the results for the data within the group.

Figures 1-1, 1-2, and 1-3 illustrate the reason for modifying the SPM infiltration rate methodology. The SPMLD infiltration rate at outdoor temperatures below the cooling design temperature is significantly reduced from the value at the design temperature. The algorithm that was derived for the

a) The 8-hour Daytime Interval

Figure 1-1. Comparison of the Infiltration Rate of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 75°F in Cooling Season in Columbia, MO

b) The 16-hour Nighttime Interval

Figure 1-1. Comparison of the Infiltration Rate of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 75°F in Cooling Season in Columbia, MO
(Cont'd)

a) The 8-hr Daytime Interval

Figure 1-2. Comparison of the Infiltration Rate of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 75°F in Cooling Season in Ft. Worth, Texas

b) The 16-hr Nighttime Interval

Figure 1-2. Comparison of the Infiltration Rate of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 75°F in Cooling Season in Ft. Worth, Texas

a) The 8-hr Daytime Interval

Figure 1-3. Comparison of the Infiltration Rate of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 75°F in Cooling Season in Caribou, Maine

b) The 16-hr Nighttime Interval

Figure 1-3. Comparison of the Infiltration Rate of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 75°F in Cooling Season in Caribou, Maine

infiltration rate, and which is plotted as the solid line labeled "improved" in these figures is as follows:

$$N(T_{db}^O) = 0.5 * (.76 + .012 * ABS (T_{db}^O - T_{db}^i)) \quad (4)$$

where 0.5 is the infiltration rate used in SPM treatment in air change/hr.

The sensible and latent loads, due to infiltration based on the infiltration algorithm, are compared with SPMLD results in Figures 2-1, 2-2, 2-3; 3-1, 3-2, and 3-3 respectively for the three climates. As these figures show, the Improved SPM can predict loads close to SPMLD results.

Figures 4-1, 4-2, and 4-3 show the comparison between solar load of SPMLD, SPM and the Improved SPM in the cooling season for the three different climates. It is apparent from the SPMLD results that the high solar load conditions correlate with low outdoor relative humidity. In the SPM treatment, the solar load is assumed to have zero value for the nighttime interval and a constant non zero value for the daytime interval equal to the solar part of fenestration load calculated by Manual J analysis. The algorithm, derived for the daytime interval for solar load and plotted as the solid lines labeled "improved" in the first part of Figures 4-1, 4-2, and 4-3, is as follows:

$$q_t^{oi} \text{ (solar, solar hours)} = DL * (1.8 - 0.005 RH^O - 0.01 (TOD - T_{db}^O)) \quad (5)$$

where DL is the solar part of fenestration load as determined by Manual J analysis in Btu/hr, RH^O is the outdoor relative humidity in percent and TOD is the summer outdoor design temperature ($^{\circ}F$).

A nonzero value of solar load is indicated by the SPMLD results in "Dark Hours" as defined in the SPM, because it is not truly dark during this interval. The algorithm, derived from the

a) The 8-hour Daytime Interval

Figure 2-1. Comparison of the Latent Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Columbia, MO

b) The 16-hour Nighttime Interval

Figure 2-1. Comparison of the Latent Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Columbia, MO
(Cont'd)

a) The 8-hr Daytime Interval

Figure 2-2. Comparison of the Latent Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas

b) The 16-hr Nighttime Interval

Figure 2-2. Comparison of the Latent Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas

Figure 2-3. Comparison of the Latent Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Caribou, Maine

Figure 3-1. Comparison of the Sensible Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Columbia, MO

b) The 16-hour Nighttime Interval

Figure 3-1. Comparison of the Sensible Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Columbia, MO

a) The 8-hr Daytime Interval

Figure 3-2. Comparison of the Sensible Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas

b) The 16-hr Nighttime Interval

Figure 3-2. Comparison of the Sensible Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas (Cont'd)

a) The 8-hr Daytime Interval

Figure 3-3. Comparison of the Sensible Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Caribou, Maine

b) The 16-hr Nighttime Interval

Figure 3-3. Comparison of the Sensible Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75° F in Caribou, Maine
(Cont'd)

a) The 8-hour Daytime Interval

Figure 4-1. Comparison of the Solar Window Heat Gain of SPMLD, SPM and Improved SPM Treatments in Columbia, MO

b) The 16-hour Nighttime Interval

Figure 4-1. Comparison of the Solar Window Heat Gain of SPMLD, SPM and Improved SPM Treatments in Columbia, MO (Cont'd)

b) The 16-hr Nighttime Interval

Figure 4-2. Comparison of the Solar Window Heat Gain of SPMLD, SPM and Improved SPM Treatments in Ft. Worth, Texas (Cont'd)

b) The 16-hr Nighttime Interval

Figure 4-3. Comparison of the Solar Window Heat Gain of SPMLD, (Cont'd) SPM, and Improved SPM Treatments in Caribou, Maine

SPMLD results plotted as the solid lines labeled "improved" in the second part of Figures 4-1, 4-2, and 4-3, is as follows:

$$q_t^{oi}(\text{solar, dark hours}) = DL * (.5 - 0.02 * (RH^O - 84) - 0.01(TOD - T_{db}^O)) \quad (6)$$

Figures 5-1, 5-2, and 5-3 show the comparison between the summation of wall, floor and door heat gain of SPMLD, SPM and Improved SPM in cooling season for three different climatic regions. The algorithm derived for this load component, which is plotted as the solid line labeled "improved" in Figures 5-1, 5-2, and 5-3, is 1.4 times the value obtained from SPM treatment.

Figures 6-1, 6-2, 6-3 show the comparison between window conduction heat gain of SPMLD and SPM in the cooling season for the three climates studied. The comparison for the ceiling load component was shown in Figures 7-1, 7-2, and 7-3. As mentioned earlier, these load components modeled in Table 5 do not change as a result of the SPMLD analysis, because SPM treatment produced acceptably accurate results.

Figures 8-1, 8-2, and 8-3 show the comparison between total cooling load of SPMLD and the Improved SPM in the cooling season for the three climates studied. As noted from these figures, the agreement between SPMLD and Improved SPM treatments is fairly good in view of the simplicity of the solar load and infiltration rate algorithms.

In order to estimate the deviation of the SPM and Improved SPM relative to SPMLD, two ratios were defined. The first ratio is:

$$ERR1 = \frac{\sum_T \sum_{RH} f(RH, T) [Q(SPMLD) - Q(IMP. SPM)] \times 100}{\sum_T \sum_{RH} f(RH, T) Q(SPMLD)} \quad (7)$$

a) The 8-hour Daytime Interval

Figure 5-1. Comparison of the Summation of Wall, Door, and Floor Heat Gain of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 75°F in Columbia, MO

b) The 16-hour Nighttime Interval

Figure 5-1. Comparison of the Summation of Wall, Door, and Floor Heat Gain of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 75°F in Columbia, MO (Cont'd)

a) The 8-hr Daytime Interval

Figure 5-2. Comparison of the Summation of Wall, Door, and Floor Heat Gain of SPMLD, SPM and Improved SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas

b) The 16-hr Nighttime Interval

Figure 5-2. Comparison of the Summation of Wall, Door, and Floor Heat Gain of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas (Cont'd)

b) The 16-hr Nighttime Interval

Figure 5-3. Comparison of the Summation of Wall, Door, and Floor Heat Gain of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 75°F in Caribou, Maine (Cont'd)

Figure 6-1. Comparison of the Window Conduction Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Columbia, MO

Figure 6-1.
(Cont'd)

Comparison of the Window Conduction Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Columbia, MO

a) The 8-hr Daytime Interval

Figure 6-2. Comparison of the Window Conduction Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas

Figure 6-2. Comparison of the Window Conduction Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas

Figure 6-3. Comparison of the Window Conduction Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Caribou, Maine

b) The 16-hr Nighttime Interval

Figure 6-3. Comparison of the Window Conduction Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Caribou, Maine

a) The 8-hour Daytime Interval

Figure 7-1. Comparison of the Ceiling Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Columbia, MO

b) The 16-hour Nighttime Interval

Figure 7-1. Comparison of the Ceiling Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Columbia, MO
(Cont'd)

a) The 8-hr Daytime Interval

Figure 7-2. Comparison of the Ceiling Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas

b) The 16-hr Nighttime Interval

Figure 7-2. Comparison of the Ceiling Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas

Figure 7-3. Comparison of the Ceiling Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Caribou, Maine

Figure 7-3. Comparison of the Ceiling Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 75°F in Caribou, Maine

a) The 8-hour Daytime Interval

Figure 8-1. Comparison of the Total Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Columbia, MO

b) The 16-hour Nighttime Interval

Figure 8-1. Comparison of the Total Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Columbia, MO
(Cont'd)

a) The 8-hr Daytime Interval

Figure 8-2. Comparison of the Total Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas

b) The 16-hr Nighttime Interval

Figure 8-2. Comparison of the Total Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Ft. Worth, Texas
(Cont'd)

a) The 8-hr Daytime Interval

Figure 8-3. Comparison of the Total Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75°F in Caribou, Maine

b) The 16-hr Nighttime Interval

Figure 8-3. Comparison of the Total Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 75° F in Caribou, Maine

where

$f(RH, T)$ = Frequency of number of hours in the cooling or heating season in the specified relative humidity and temperature bin.

$Q(IMP.SPM)$ = cooling or heating calculated by Improved SPM method at each specific relative humidity and temperature bin.

$Q(SPMLD)$ = cooling or heating load calculated by SPMLD at each specific relative humidity and temperature bin.

The denominator of this equation represents the total cooling or heating load during the cooling or heating season calculated by the SPMLD technique, while the numerator represents the difference between the cooling or heating load values, each calculated by a separate technique (SPMLD or Improved SPM). The ratio (ERR1) represents the percentage difference between the cooling or heating loads for the whole cooling or heating season. This ratio estimates the variation in a building's energy consumption during a cooling or heating season, if the building load calculation is performed by the Improved SPM technique, rather than an hourly computer simulation technique, such as SPMLD.

The other ratio (EER2), the percentage load difference between the two methods averaged over all relative humidity and temperature bins, determines how close is the agreement between Improved SPM load model and the SPMLD, when they are plotted as functions of outdoor dry-bulb temperature bins with relative humidity bin as a parameter. This ratio is defined as:

$$ERR2 = \sum_T \sum_{RH} f(RH, T) \left[1 - \frac{Q(IMP. SPM)}{Q(SPMLD)} \right] * \frac{Q(SPMLD)}{QMJ} \times 100 \quad (8)$$

where QMJ is the Manual J cooling or heating load. This ratio has a weighting factor of $Q(SPMLD)/QMJ$ to reflect the large differences between SPMLD and Improved SPM at high cooling or heating load points. (The high load points are points where $Q(SPMLD)$ is close to QMJ).

These two ratios have been calculated for three different climatic regions. Table 9 shows these ratios for cooling load calculation, in which the SPM and Improved SPM are compared with SPMLD. This table is based on 8-hour "Solar-Hour" and a 75°F indoor temperature. The numbers in this table are the average of "Solar Hours" and "Dark Hours". As shown, the deviations from SPMLD have improved considerably due to improvements in the cooling SPM load model, especially in the climatic regions with higher cooling loads.

5.2 HEATING

The comparison, made between SPMLD and SPM for the three climates studied, results in changes in the SPM heating load model in order to improve heating load estimates.

In the improved treatment, the total heat loss, which is only sensible, has been separated into two components -- sensible infiltration heat loss and a component containing conduction, solar and sensible internal loads.

Figures 9-1, 9-2, and 9-3 show comparisons between the infiltration rate of the SPMLD and Improved SPM during the

Table 9. Percentage Difference of Total Cooling Load of SPM and Improved SPM Relative to SPMLD for Three Different Climatic Regions With Indoor Temperature of 75°F Averaged Over Day and Night Intervals

	ERR1		ERR2	
Location	SPM	Improved SPM	SPM	Improved SPM
Caribou, ME	14.8	-4.3	63	-15.7
Columbia, MO	10.1	- .9	29.4	- 5
Ft. Worth, TX	10.8	-1.6	23.3	- 9.4

Figure 9-1. Comparison of the Infiltration Rate of SPMLD Averaged Over 24-Hour Interval and the Infiltration Rate Model at an Indoor Temperature of 70°F in Heating Season in Columbia, MO

Figure 9-2. Comparison of the Infiltration Rate of SPMLD Averaged Over 24-Hour Interval and the Infiltration Rate Model at an Indoor Temperature of 70°F in Heating Season in Ft. Worth, Texas

Figure 9-3. Comparison of the Infiltration Rate of SPMLD Averaged Over 24-Hour Interval and the Infiltration Rate Model at an Indoor Temperature of 70°F in Heating Season in Caribou, Maine

heating season in three different climatic regions. Although these figures are plotted for different relative humidity bins, the infiltration rate does not depend on relative humidity and the scatter in these figures is due to different wind speeds. The SPMLD infiltration rate at outdoor temperatures above the heating design temperature is significantly reduced from the value at the design temperature. The algorithm derived for infiltration rate, and plotted as the solid line in Figures 9-1, 9-2, and 9-3 is as follows:

$$N(T_{db}^O) = 0.5 (.9 + 0.0135 \text{ ABS } (T_{db}^i - T_{db}^O)) \quad (9)$$

The sensible heat loss due to infiltration based on the infiltration algorithm in the three regions is compared with SPMLD results in Figures 10-1, 10-2, and 10-3, where they are in good agreement.

Figures 11-1, 11-2 and 11-3 show the comparison between the second component of heat loss (total loss - infiltration heat loss) of SPMLD and Improved SPM in heating season for the three climatic regions. The algorithm derived for this component and plotted as the solid line in Figures 11-1, 11-2, and 11-3, is as follows:

$$q = .65 \times (\text{Manual J heating load}) \times \frac{60 - T_{db}^O}{60 - T_{OD}} \quad (10)$$

i.e., it is a linear fit that has a value of 65% of the design load at the outdoor design temperature and zero value at 60°F.

The implication appears to be that solar and internal heat gains cause the zero load temperature to be 10°F below the indoor temperature.

Figure 10-1. Comparison of Sensible Infiltration Heat Loss of SPMLD Averaged Over 24-Hour Interval and the Load Based on Infiltration Model at an Indoor Temperature of 70°F in Columbia, MO

Figure 10-2. Comparison of Sensible Infiltration Heat Loss of SPMLD Averaged Over 24-Hour Interval and the Load Based on Infiltration Model at an Indoor Temperature of 70°F in Ft. Worth, Texas

Figure 10-3. Comparison of Sensible Infiltration Heat Loss of SPMLD Averaged Over 24-Hour Interval and the Load Based on Infiltration Model at an Indoor Temperature of 70°F in Caribou, Maine

Figure 11-1. Comparison of the Total Heat Loss Minus Heat Loss Due to Infiltration of SPMLD Averaged Over 24-Hour Interval and Improved SPM at an Indoor Temperature of 70°F in Columbia, MO

Figure 11-2. Comparison of the Total Heat Loss Minus Heat Loss Due to Infiltration of SPMLD Averaged Over 24-Hour Interval and Improved SPM at an Indoor Temperature of 70°F in Ft. Worth, Texas

Figure 11-3. Comparison of the Total Heat Loss Minus Heat Loss Due to Infiltration of SPMLD Averaged Over 24-Hour Interval and Improved SPM at an Indoor Temperature of 70°F in Caribou, Maine

The ASHRAE 1977 Fundamentals (Reference 5) provide an example of an insulated residence (our sample residence is insulated) for which heat loss due to infiltration is about 37.4% of the design load where internal loads are not considered and where the design air infiltration rate is approximately 1 air change/hr. Since the internal load is accounted for in our calculation, the result (infiltration load equals 35% of the total heating load at design condition) is in close agreement with the ASHRAE example.

Figures 12-1, 12-2, and 12-3 show the comparisons between the total heating load of SPMLD, SPM, and the Improved SPM during the heating season for the three climates. It appears from these figures, the agreement is fairly good in view of the simplicity of the model.

Table 10 shows ERRI and ERR2 calculated for the heating load in which SPM and Improved SPM have been compared with SPMLD during the heating season. These ratios have been given for the three different climatic regions. This table is based on an indoor dry-bulb temperature of 70°F. The deviations from SPMLD have decreased due to improvements in the heating SPM load model, especially in the climatic regions with higher heating loads.

Figure 12-1. Comparison of the Total Heat Loss of SPMLD Averaged Over 24-Hour Interval, SPM and Improved SPM at an Indoor Temperature of 70°F in Columbia, MO

Figure 12-2. Comparison of the Total Heat Loss of SPMLD Averaged Over 24-Hour Interval, SPM and Improved SPM at an Indoor Temperature of 70°F in Ft. Worth, Texas

Figure 12-3. Comparison of the Total Heat Loss of SPMLD Averaged Over 24-Hour Interval, SPM and Improved SPM at an Indoor Temperature of 70°F in Caribou, Maine

Table 10. Percentage Difference of Total Heating Load of SPM and Improved SPM Relative to SPMLD for Three Different Climatic Regions With Indoor Temperature of 70°F

Location	ERR1		ERR2	
	SPM	Improved SPM	SPM	Improved SPM
Caribou, ME	5	2	9	4
Columbia, MO	-3	-2	-7	-5
Ft. Worth, TX	-10	-6	-28	-17

6.0 CONCLUSION

The results obtained indicate that a fairly good agreement exists between the SPMLD and Improved SPM treatments for both cooling and heating load calculations for a wide range of heating and cooling degree days. These results have been obtained using three different climatic regions where heating and cooling degree days range between 2,000 and 10,000 and 100 to 2,500 respectively, based on 65°F. The percentage difference of total cooling and heating load, based on the Improved SPM load model relative to SPMLD (ERRI), is less than 1% and 2% respectively for Columbia, Missouri. Columbia, Missouri meteorological characteristics are very similar to Kansas City where approximately the same total electrical energy is input to the air conditioners and the same indoor relative humidity exists as the average over the 12 U.S. sites (Reference 2).

The procedure used to calculate the cooling and heating load of a residence according to the Improved SPM is briefly discussed below.

Cooling

1. Determine summer outdoor design temperature.
2. Determine the following load components at the outdoor design condition for a specified indoor dry-bulb temperature by Manual J analysis
 - Solar Fenestration
 - Air/Air Fenetration
 - Conduction segment of walls and doors
 - Ceiling
3. Estimate the sensible and latent loads due to people and appliances in the residence.
4. Determine the following load components for each outdoor dry-bulb temperature bin and for each outdoor relative humidity bin for specified indoor

design conditions by respective algorithms. (There are six different outdoor relative humidity bins.)

- Solar Fenestration
 - Air/Air Fenestration
 - Conduction segment of walls and doors
 - Ceiling
 - Sensible load due to infiltration
 - Latent load due to infiltration (The value of average outdoor relative humidity in each relative humidity bin is required for this calculation.)
5. Determine the cooling load at each outdoor relative humidity bin, and each outdoor dry-bulb temperature bin by summing all the above-mentioned components, and sensible and latent internal loads.
 6. Determine the total cooling load at each outdoor temperature bin for a cooling season by multiplying the cooling load at each outdoor relative humidity bin by the number of hours in that bin and then sum over six relative humidity bins. The number of hours in each relative humidity bin for each location could be obtained from NOAA.
 7. Determine the total cooling load for a cooling season by summing the total cooling load at each outdoor temperature bin over those temperature bins, which results in heat gain.

Heating

1. Determine winter outdoor design temperature.
2. Determine the heating load at the outdoor design condition for a specified indoor dry-bulb temperature by Manual J analysis.
3. Determine the sensible infiltration load component for each outdoor dry-bulb temperature bin through its algorithm.
4. The rest of the heating load components (total load - sensible infiltration load) at the design condition will be equal to .65 times Manual J heating load value at the design condition and it will be zero for 60°F outdoor dry-bulb temperature assuming an indoor temperature of 70°F. For other outdoor temperature bins, this component is modeled as straight line connecting the heating load at the

design condition with zero load at 60°F outdoor temperatures, assuming an indoor temperature of 70°F. For other indoor temperatures, the heating load line is simply raised or lowered to reflect the temperature differential at each outdoor dry-bulb temperature. The linear nature of the load line is maintained.

5. Determine the heating load at each outdoor dry-bulb temperature bin by summing the two components.
6. Determine the total heating load at each outdoor dry-bulb temperature bin for a heating season by multiplying the heating load at each outdoor dry-bulb temperature bin by the number of hours in the bin. The number of hours in each temperature bin for each location could be obtained from NOAA.
7. Determine the total heating load for a heating season by summing up the total heating load at each outdoor temperature bin over those temperature bin which results in heat loss.

7. REFERENCES

1. _____ "Cooling and Heating Load Improvements in Seasonal Performance Modeling of Room and Central Air Conditioners and Heat Pumps," Contract DE-AC03-79-CS10757, SAI-444-80-299-LJ, March 1980.
2. Rettberg, R.J., ASHRAE Transactions, Volume 86, Part 1, 1980.
3. _____ "Manual J: Load Calculation for Residential Winter and Summer Air Conditioning." National Environmental Systems Contractors Association, Alington, Virginia, 1975.
4. _____ Air Force, Army and Navy Manual: Engineering Weather Data, AFM 88-8, Chapter 6. Department of the Air Force, The Army and The Navy, 15 June 1967.
5. _____ ASHRAE Handbook and Product Directory: 1977 Fundamentals, Chapter 24, American Society of Heating, Refrigerating and Air Conditioning Engineers, 1977.

APPENDIX A

MANUAL J ANALYSIS FOR
COOLING AND HEATING LOADS CALCULATION

APPENDIX A

MANUAL J ANALYSIS FOR COOLING AND HEATING LOADS CALCULATION

In order to compare the results obtained from SPMLD for cooling and heating loads, a Manual J calculation was made for cooling and heating loads for the sample residence in Columbia, Missouri at the design conditions.

Heat Transfer Multipliers (HTM) are shown in Tables A-1 and A-2 for cooling and heating load calculations, respectively. Manual J design cooling load calculations for the sample residence in Columbia, Missouri are shown in Table A-3. A cooling load of 19740 Btu/hr is required for the design condition.

ARI 230 separates fenestration load (window load) into solar heat gain and air/air (window conduction) as follows:

$$\begin{aligned}\text{Air/Air (for double glass)} &= 7 \times \text{window area} \\ &= 7 \times 130 = 910 \text{ Btu/hr}\end{aligned}$$

$$\text{Solar} = \text{Window-Air/Air} = 6500 - 910 = 5590 \text{ Btu/hr.}$$

ARI 230 also separates infiltration from transmission (conduction) for walls and doors as follows:

$$\begin{aligned}\text{Infiltration} &= 1.5 (\text{Total wall and door area}) \\ &= 1.5 (1303 + 40) = 2014 \text{ Btu/hr}\end{aligned}$$

$$\begin{aligned}\text{Conduction} &= \text{Total load-infiltration} \\ &= 4429 - 2014 = 2415\end{aligned}$$

A Manual J heating design load calculation for the example residence in Columbia, Missouri is shown in Table A-4.

Table A-5 shows the result of Manual J cooling and heating load calculations for the three different climates.

Table A-1. Heat Transfer Multipliers for Cooling for the Example Residence in Columbia, Missouri (Outdoor Design Temperature of 95°F)

COMPONENT	HTM
Double Glass West & East (Draperies or Venetian Blinds)	50
Storm Doors	13*
Walls (R-11 insulation)	3*
Ceiling (R-19 insulation)	2
Floor (no edge insulation)	0

* These factors include transmission and infiltration

Table A-2. Heat Transfer Multipliers for Heating for the Example Residence in Columbia, Missouri (Design Temperature Difference of 65°F)

COMPONENT	HTM
Double Glass	65*
Storm Doors	155*
Wall (R-11 insulation)	5*
Ceiling (R-19 insulation)	3
Floor (no edge insulation)	55

* These factors include transmission and infiltration at wind speed of 15 mph.

Table A-3. Manual J Design Cooling Load Data for the Example Residence in Columbia, Missouri

PARAMETERS	VALUE	NOTES
Design Temperatures		
Outdoor Temperature (TOD)	95°F	TIN = 75°F is standard for Manual J Heat Transfer Multipliers (HTM's)
Indoor Temperature (TIN)	75°F	
Daily Temperature Range	M	
Load according to Manual J		
Windows	6,500	
Doors	520	HTM include infiltration
Walls	3,909	HTM include infiltration
Ceiling	1,556	
Floors	0	
People	1,500	At 300 Btu/hr each person
Appliances	1,200	1 kitchen appliance load @ 1,200 Btu/hr
Sensible Gain	15,185	
(Implied Latent Gain)	4,555	At 30% of Sensible Heat Gain
Total Gain	19,740 Btu/hr	

Table A-4. Manual J Design Heating Load Data for the Example Residence in Columbia, Missouri

PARAMETERS	VALUE
Design Temperatures	
Outdoor Temperature	5°F
Indoor Temperature	70°F
Daily Temperature Range	M
Load according to Manual J	
Windows	8,450
Doors	6,200
Walls	6,515
Ceiling	2,334
<u>Floor</u>	<u>6,050</u>
Total Sensible	29,549 Btu/hr

Table A-5. Summer and Winter Outdoor Design Temperature (SODT, WODT) and Manual J Design Cooling and Heating Load (SQMJ, WQMJ) for the Three Different Climates Studied

	Caribou, Maine	Columbia, Missouri	Ft. Worth Texas
SODT (°F)	80	95	100
SQMJ (Btu/hr)	14580	19740	21590
WODT (°F)	-15	5	20
WQMJ (Btu/hr)	-36680	-29549	-23018

APPENDIX B

COMPARISON OF COOLING LOADS OF SPMLD AND IMPROVED
SPM AT 80°F INDOOR DRY-BULB TEMPERATURE

APPENDIX B

COMPARISON OF COOLING LOADS OF SPMLD AND IMPROVED SPM AT 80°F INDOOR DRY-BULB TEMPERATURE

This appendix presents the results obtained in the text for cooling loads and an 80°F indoor dry-bulb temperature. These results, presented for Colombia, Missouri and Fort Worth, Texas, have not been reproduced for Caribou, Maine, because summer outdoor design condition in this location is 80°F and therefore is not of any significance.

The total heat gain results for 80°F indoor temperature, closely resemble those derived for a 75°F indoor temperature and they agree reasonably well with SPMLD treatment.

a) The 8-hour Daytime Interval

Figure B-1-1. Comparison of the Infiltration Rate of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 80°F in Cooling Season in Columbia, MO

b) The 16-hour Nighttime Interval

Figure B-1-1. Comparison of the Infiltration Rate of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 80°F in Cooling Season in Columbia, MO

a) The 8-hour Daytime Interval

Figure B-2-1. Comparison of the Latent Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 80°F in Columbia, MO

b) The 16-hour Nighttime Interval

Figure B-2-1. Comparison of the Latent Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 80°F in Columbia, MO
(Cont'd)

a) The 8-hr Daytime Interval

Figure B-2-2. Comparison of the Latent Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 80°F in Ft. Worth, Texas

b) The 16-hr Nighttime Interval

Figure B-2-2. Comparison of the Latent Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 80°F in Ft. Worth, Texas (Cont'd)

a) The 8-hour Daytime Interval

Figure B-3-1. Comparison of the Sensible Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 80°F in Columbia, MO

b) The 16-hour Nighttime Interval

Figure B-3-1. Comparison of the Sensible Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 80°F in Columbia, MO
(Cont'd)

a) The 8-hr Daytime Interval

Figure 3-3-2. Comparison of the Sensible Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 80°F in Ft. Worth, Texas

b) The 16-hr Nighttime Interval

Figure 3-3-2. Comparison of the Sensible Infiltration Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 80°F in Ft. Worth, Texas

a) The 8-hour Daytime Interval

Figure B-4-1. Comparison of the Summation of Wall, Door, and Floor Heat Gain of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 80°F in Columbia, MO

b) The 16-hour Nighttime Interval

Figure B-4-1. Comparison of the Summation of Wall, Door, and Floor Heat Gain of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 80°F in Columbia, MO (Cont'd)

a) The 8-hr Daytime Interval

Figure B-4-2. Comparison of the Summation of Wall, Door, and Floor Heat Gain of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 80°F in Ft. Worth, TX

b) The 16-hr Nighttime Interval

Figure B-4-2. Comparison of the Summation of Wall, Door, and Floor Heat Gain of SPMLD, SPM, and Improved SPM Treatments at an Indoor Temperature of 80°F in Ft. Worth, TX (Cont'd)

a) The 8-hour Daytime Interval

Figure B-5-1. Comparison of the Window Conduction Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 80°F in Columbia, MO

b) The 16-hour Nighttime Interval

Figure B-5-1. Comparison of the Window Conduction Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 80°F in Columbia, MO

a) The 8-hr Daytime Interval

Figure B-5-2. Comparison of the Window Conduction Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 80°F in Ft. Worth, Texas

b) The 16-hr Nighttime Interval

Figure B-5-2. Comparison of the Window Conduction Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 80°F in Ft. Worth, Texas

a) The 8-hour Daytime Interval

Figure B-6-1. Comparison of the Ceiling Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 80°F in Columbia, MO

b) The 16-hour Nighttime Interval

Figure B-6-1. Comparison of the Ceiling Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 80°F in Columbia, MO

a) The 8-hr Daytime Interval

Figure B-6-2. Comparison of the Ceiling Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 80°F in Ft. Worth, Texas

b) The 16-hr Nighttime Interval

Figure B-6-2. Comparison of the Ceiling Heat Gain of SPMLD and SPM Treatments at an Indoor Temperature of 80°F in Ft. Worth, Texas

a) The 8-hour Daytime Interval

Figure B-7-1. Comparison of the Total Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 80°F in Columbia, MO

b) The 16-hour Nighttime Interval

Figure B-7-1 Comparison of the Total Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 80°F in Columbia, MO
(Cont'd)

a) The 8-hr Daytime Interval

Figure B-7-2. Comparison of the Total Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 80°F in Ft. Worth, Texas

b) The 16-hr Nighttime Interval

Figure B-7-2. Comparison of the Total Heat Gain of SPMLD and Improved SPM Treatments at an Indoor Temperature of 80°F in Ft. Worth, Texas
(Cont'd)