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Validation Tests of the Thermal Analysis Research Program

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

ABSTRACT

In this study analytical and empirical tests were performed using the Thermal Analysis Research Program (TARP). TARP was found to be very accurate relative to the analytical tests (calculations for simplified conditions) which covered steady and transient conduction, internal radiant interchange, latent loads, and clear sky solar gains. Six one-room buildings with different wall constructions provided data for the empirical tests. TARP's predicted heating loads were generally within 10 per cent of the predicted heating loads. The prediction of cooling loads was less successful with an average difference from the measured loads of 25 per cent. This error was considered primarily due to uncertainties in the measured cooling loads and the modeling of diffuse solar gains. The analytic tests are now part of the information available on the TARP source code tape.

PREFACE

This report is one of a series documenting NBS research and analysis efforts in developing energy and cost data to support the Department of Energy/National Bureau of Standards Measurements Program. It was prepared by the Thermal Analysis Group, Building Physics Division, Center for Building Technology, National Engineering Laboratory, National Bureau of Standards (NBS). This work was jointly sponsored by NBS and DoE. The development of multi-room airflow modeling was supported by DoE/NBS Task Order A008 under Interagency Agreement Number E-77-A-01-6010. This report describes calculations and a computer program which were written as part of an effort to develop a comprehensive modeling technique for predicting the simultaneous transfer of heat, moisture, air, and contaminants in and through multi-room buildings.

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1. INTRODUCTION

This report presents the results of tests to validate the Thermal Analysis Research Program (TARP) [1]. As introduced by NBS in March, 1983, TARP is a unique building thermal load prediction program which performa a simultaneous evaluation of air, moisture, and heat transfer in and through multi-room buildings as affected by dynamic external conditions and internal loads. TARP is an evolutionary development of the more user oriented BLAST [2] computer program. Primary emphasis has been on additional algorithms, flexibility in modeling the building, and program portability to other computers. TARP has been used on Sperry, CDC, IBM, and DEC (VAX) computers.

Although a prospective TARP user would like to have high confidence in its accuracy, validation of any large computer program is a difficult task. This is particularly true of building energy analysis programs which contain hundreds of variables, parameters, and algorithms. Even if each algorithm is validated individually, with each parameter tested at maximum and minimum values, there is no guarantee that some combination of algorithms will not give an improper result because of some unexpected interaction. In addition, the heat transfer algorithms and particularly the correct parameters to use in those algorithms are still considered to be areas of continuing research.

Inaccurate results are not always due to program errors as shown in the SERI report [3] which identified seven error sources classified into two groups. External error sources are those which are not under the control of the developer of the computer code. These errors include:
1. differences between the actual weather around the building and the weather input used with the simulation;
2. differences between the actual effect of occupant behavior and those effects assumed by the user;
3. user error, including inappropriate simplifying assumptions, in deriving the input files;
4. differences between the actual thermal and physical properties of the building and those input by the user.

Internal error sources are those contained within the coding of the program. They Include:
1. differences between the actual heat/mass transfer mechanisms and the algorithmic representations of those mechanisms;
2. differences between the actual interactions of heat/mass transfer mechanisms and those interactions between the algorithms;
3. coding errors.

Only the internal errors can be identified in general testing. The external errors occur on a case by case basis although the input procedures, documentation, and internal data checking can assist in reducing user errors.

Three types of tests have been used to validate building energy analysis programs. One is comparison to other simulation programs. Another is comparison to analytically calculated results. The third is comparison to experimental data. The following table from the SERI validation report [3] summarizes the advantages and disadvantages of each method.

VALIDATION TECHNIQUES

Technique	Advantages	Disadvanteges
Comparative Relative test of different programs	No input uncertainty Any level of complexity Inexpensive Quick: many comparisons possible	No truth standard
Analytical Test of numerical solution	No input uncertainty Exact truth standard given the simplicity of the model Inexpensive	Does not test the model Limited to cases for which analytical solutions can be derived
Empirical Comparison to measured building performance	Approximate truth standard within accuracy of data acquisition Any level of complexity	Measurement involves some degree of input uncertainty High quality, detailed measurements are time consuming & expensive A limited number of data sites and configurations are economically practical

In this report both analytical and empirical comparisons will be presented.

2. ANALYTIC TESTS

One set of standards against which the simulation program can be tested are those which have analytical solutions. These cases must be much simpler than those encountered in real buildings. (If analytic solutions existed for real building conditions, there would be no need for computer simulation.) They are especially useful in determining the existance of coding errors. For that reason such tests may also be considered "software validation". They prove that the program is doing what was intended in the heat transfer analysis and in the handling of input and output (I/O). The current version of TARP has some 22.000 lines of FORTRAN code and comments. The majority of these lines deal with I/O. Therefore, the analytic tests have been devised to test the I/O as well as the heat transfer algorithms.

It is best for the test algorithm to be independent of the TARP algorithm -- they should use different methods to compute the answer. This helps to insure that proper energy (and mass transfer, etc.) values are being computed instead of just showing that the computer does correct arithmetic for the TARP algorithm. This requires some knowledge of how the program works in order to know if different algorithms are being tested. However, it does present the danger that subconsciously tests may be devised so that the program can pass. Although the analytic tests given below are designed to exercise TARP and not to develop general test procedures for all building energy analysis programs. the principal ideas behind the tests could be applicable to other programs.

It should be understood at the outset that TARP is undergoing continual revision because it is a research program. New algorithms are added; old ones are modified. Although much effort has gone into making the program modular, there is considerable interaction among the algorithms. Whenever a change is made, it is important to prove that other calculations have not been inadvertantly affected. The following set of test cases can serve to check for such inadvertant changes.

Input files for the analytic validation tests are listed in Appendix A. One special feature of TARP input is that it can (and usually should) include "comments". Any text on a line after a dollar sign ($) is ignored by the TARP input processor and can be used as a "comment". The validation input files are extensively commented. They include the expected results of the simulation. These results are arrived at by procedures independent of TARP, which are documented in the comments. Occasionally TARP and the simple analytical algorithms produce different results. Such differences must be reasonable based upon known differences between TARP and the simple algorithms. The complexity of the problem may not allow development of a complete analytic solution. Then the analytic tests should show the limits of the correct solution and demonstrate reasonable trends. The reader is directed to Appendix A for the details of each analytic test.

2.1 Steady Conduction and Scheduled Loads Tests

The simplest analytic tests occur with steady state conditions. Input file BDP-1 (pages A-1 to A-3) tests the steady state conduction calculation which uses the conduction transfer functions (CTF), and it tests that the user schedulable loads are correctly processed in the calculation of room heating and cooling loads. The CTF method was developed to model transient heat conduction. The computed results agree with the predictions to the limits of accuracy in the printed results except for infiltration. In the case of infiltration there is 0.1% difference because the density of air is assumed to be a constant .075 lb/ft^3 ($1.2\ kg/m^3$) in computing the analytic solution. TARP uses a more general model where air density is a function of temperature and pressure.

2.2 Transient Conduction Tests

The use of CTF to calculate transient heat conduction is tested by comparing to an analytic solution for the surface temperatures of walls as they respond to a step change in air temperature. This used input file BDP-2 (pages A-4 to A-8). Two of the tests were developed by the author and three at SERI. This test demonstrates a case where the limiting values instead of the exact solution is computed. The test is a refinement of the SERI procedure. Only the very thin wall ever goes outside the limits. This error is demonstrating a true limit of the CTF method — too few CTF coefficients are calculated for thin walls to permit exact modeling of the transient conduction. There is also a limit on the maximum thickness of a wall, which is not reached in these tests.

2.3 Radiant Interchange Tests

BDP-3 (pages A-9 to A-11) is an input file for testing radiant interchange calculations which use the mean radiant temperature (MRT) network method [4]. Manual loads calculation methods typically ignore radiant heat transfer, or at least only lump it in with convective heat transfer between the walls and the air. Detailed modeling of radiant transfer is possible in computer simulations but it is time consuming. especially for rooms with large numbers of surfaces. The MRT network method is a fast algorithm which approximates radiant heat transfer, included its nonlinear nature. The results of this test are accurate to the limits of the printed output. i.e. 4 digits. The MRT network method is known to produce a correct radiation interchange factor for this simple geometry. It is also known to be only approximate for more complex geometries.

2.4 Latent Loads and Contaminant Tests

Latent loads and contaminant concentrations are calculated by very similar algorithms involving an Euler (standard explicit) integration at a much shorter timestep than one hour. Input file BDP-4 (pages A-12 to A-14) tests these calculations. The steady state and transient results are accurate to within 0.1% at the default 60 second timestep. Other tests indicate very little loss in accuracy of the hourly moisture and contaminant concentrations with timesteps as long as six minutes, although the intermediate transient results have relatively large errors.

2.5 Solar Gains Tests

Data in the AHSRAE handbooks are used to study the solar gain calculations which are tested with input file BDP-5 (pages A-16 to A-19). The position of the sun, the intensity of clear sky solar radiation, and the design solar gain values can be compared. There are differences of up to 3% in the solar gains values. This is caused primarily by ASHRAE (1977 Fundamentals Handbook. page 26.26) using a nonisotropic diffuse radiation distribution while TARP uses an isotropic distribution. The nonisotropic algorithm has not been included in TARP because it applies only to unshaded vertical surfaces, and TARP allows any surface tilt and shadowing.

2.6 Other Tests

Although tests of several other algorithms have been performed, they are either incomplete or only partially documented. One test studied the geometric processing of the room surfaces as they undergo various coordinate transformations (translation. rotation. and mirror imaging). The primary output is the sketch of the surfaces. This sketch is also a help in preventing user errors. Another test studied the shadowing calculations. It involved a simple box shaped room with windows on the north and south sides and various opaque and partially transparent shadowing surfaces around the south window. Calculations produced the correct shadow geometries and permitted sunlight to pass through the room at time when the sun was in the correct position. The detailed airflow calculations were tested by comparison to an analytic procedure for flows through openings in series and/or parallel with each other. The simple vent fan, whole house fan, and interzone mixing models were tested to show appropriate trends in their results. These tests will be made available on the TARP source tape when they are completed.

3. EMPIRICAL TESTS

Experiments provide data which can validate the algorithms used in the simulation program. TARP simulation results were compared to data from six NBS test buildings [5,6]. The buildings were constructed to determine the effects of wall thermal mass on heating and cooling loads. The test buildings were simple 6.1 by 6.1 m (20 by 20 ft) one room structures located at Gaithersburg, Maryland (fig. 1). They all had the same floor plan and orientation. They were identical except for exterior wall constructions which were: (1) insulated wood frame, (2) uninsulated wood frame, (3) insulated masonry, (4) uninsulated masonry, (5) log, and (6) insulated masonry with the mass inside the insulation. Full descriptions of these buildings are given in reference [5]. The buildings were instrumented to determine heating and cooling loads, wall heat transmission, and indoor temperature and humidity. The floors were covered with 2 in (51 mm) thick polystyrene insulation to reduce the effect of heat transfer to the ground. Eleven inches of glass-fiber blanket insulation was installed over the ceiling. Each building had four triple glazed windows. There was a constant internal heat gain of 290 W. These factors plus the high ratio of wall area to floor area create buildings having a high sensitivity to wall heat transfer. The buildings were studied during a winter heating season, a mild heating (spring) season, and a summer cooling season.

3.1 Comparison for the Winter Test Period

The winter heating test covers a period from February 21, 1982 through March 5. Although all days are simulated by TARP, only the last three days are used for comparison with the measured data. This insures that transients from prior to the start of the simulation are not part of the comparision period. Figure 2 shows the values measured for ambient temperature and total horizontal solar radiation for the comparison period. Figure 3 is a summary of the predicted and measured heating loads for the comparison period. Figures 4 through 9 give the hourly heating loads for the six buildings. The following table summarizes the differences between the TARP predictions and the measured heating loads in three ways: (1) the root mean square deviation of the hourly loads, (2) the difference in the average hourly load for the entire test period for each building, and (3) the difference in the combined average loads of all buildings.

Winter Test Period	House 1	House 2	House 3	House 4	House 5	House 6
Error (RMS) in hourly heating loads	14.6 %	11.4 %	17.1 %	24.5 %	10.1 %	19.0 %
Average measured load	569 W	1208 W	626 W	1053 W	589 W	706 W
Average predicted load	554 W	1280 W	541 W	1262 W	620 W	620 W
Error in average load	- 2.7 %	+ 6.0 %	-13.4 %	+19.8 %	+ 5.2 %	-12.2 %

Average for all six buildings: 804 W 813 W +1.1 %
(measured, predicted, error)

3.2 Comparison for the Spring Test Period

The spring heating test covers a period from April 11. 1982 through April 25. Only the last four days are used for comparison. The weather for the comparison period is shown in figure 10, and the summary of heating loads is shown in figure 11. Figures 12 through 17 show the hourly measured and predicted heating loads for all six buildings. The differences between the measured and predicted heating loads are summarized in the following table.

Spring Test Period	House 1	House 2	House 3	House 4	House 5	House 6
Error (RMS) in hourly heating loads	76.4 %	30.0 %	82.2 %	49.7 %	64.5 %	105. %
Average measured load	163 W	441 W	136 W	256 W	104 W	88 W
Average predicted load	129 W	405 W	95 W	330 W	103 W	49 W
Error in average load	-20.8 %	- 8.2 %	-30.0 %	+29.0 %	- 0.8 %	-44.1 %

Average for all six buildings: 198 W 185 W -6.5 %
(measured, predicted, error)

3.3 Comparison for the Summer Test Period

The summer cooling test covers a period from July 23, 1982 through August 5. Only the last three days are used for comparison. The weather for the comparison period is shown in figure 18, and the summary of cooling loads is shown in figure 19. Figures 20 through 25 show the hourly measured and predicted cooling loads for each building. The differences between the measured and predicted cooling loads are summarized in the following table:

Summer Test Period	House 1	House 2	House 3	House 4	House 5	House 6
Error (RMS) in hourly cooling loads	32.7 %	32.2 %	50.6 %	51.1 %	34.4 %	40.8 %
Average measured load	409 W	572 W	320 W	373 W	332 W	283 W
Average predicted load	473 W	617 W	437 W	507 W	404 W	334 W
Error in average load	+15.6 %	+ 7.8 %	+36.6 %	+35.9 %	+21.6 %	+18 1 %

Average for all six buildings: 361 W 462 W +21 %
(measured, predicted, error)

3.4 Discussion

In addition to the wide variability in error for each building, there are two trends in the comparisons. First, the accuracy improves as more data is averaged together before the measured and predicted performances are compared. This is an indication of the extent to which the errors are random, i.e. if they are perfectly random, averaging large amounts of measured and simulated data would give the same results. The method used to compute beam and diffuse solar radiation given the total horizontal radiation is an example of a TARP algorithm which leads to such random errors. Each value of total horizontal solar radiation (for a given solar altitude and time of year) leads to single values of beam and diffuse radiation, even though differing sky conditions cause a wide variation in beam and diffuse radiation which could lead to the same total horizontal value. These differences have been averaged out in deriving the algorithm used in TARP. Second, the average error for all buildings combined goes from 9 W too little predicted heat gain (or too much heat loss) in the winter, to 13 W too much heat gain in the spring, to 80 W too much heat gain in the summer. This indicates a non-random component in the modeling error.

The thermal properties of the walls are about 10 per cent accurate based on several measures: properties reported by ASHRAE, hot box measurements of similar walls, and comparisons of measured to predicted heat loss under weather conditions approaching those where steady state theory is applicable. The high discrepancy of building 6 is at least partially due to insulation voids under the windows and a thermal bridge from the inside thermal mass to the ground. The framing fraction (portion of the wall which is framing material instead of insulation and therefore highly conducting) is estimated rather than measured. The thermostat set points used in TARP were determined from average midheight room air temperature in each house, which did not account for the gradients in the room air temperature. The energy used for heating is accurate within 0.25 per cent because electric heaters were used. The accuracy of the measured sensible cooling load is more prone to error because it was done by measuring the airflow rate in the duct and the air temperature before and after the cooling coil. The airflow measurement was up to 8 per cent uncertain and the temperature difference measurement up to 4 per cent, giving an upper limit to the overall uncertainty of perhaps 12 per cent. The cyclic nature of the equipment accounts for some of the variability in the measured hourly loads. Consider a hypothetical case where the air conditioner is on for three 20 minute periods and off for three 20 minute periods in two hours. This means twice the energy consumption is reported in one hour as in the other even though the heat gain to the building could be constant.

A significant case of user input error occurred in developing the input files. The overhang, which shades the window in the spring and summer seasons, was placed below the windows in the input file. This was later discovered and corrected during a review of the input data. The placement of overhangs does not appear on any graphic output like the feature which draws a very simple plan view of the walls, floors, and ceilings. This feature has been invaluable in checking the geometric description of such surfaces. The error on the overhang placement indicates a need for more graphic output to assist the user.

While correcting the overhang problem, the view factor between the walls and the sky as reduced by the overhang was determined. Using the reduced view factor, instead of the default value, gave about a 5% improvement in the spring and summer loads. The typical user would probably not compute specific view factors. The reduction in view factor due to the adjacent buildings and trees can not be done by a simple calculation, but it also appears to be significant. This additional reduction has not been included in the comparison because the typical user could not compute it. In addition, it raises questions about the error introduced by considering the diffuse solar radiation to be of uniform intensity from every point in the sky, since it is known to be nonuniform. More detailed descriptions [7] are very difficult to implement in a simulation with shadowing features. The accuracy of the diffuse radiation value is more important in the spring and summer for the test houses because the overhang blocks direct solar gains. Solar gains are more important in the test buildings than in most buildings because of the envelope dominance on the loads.

4. SUMMARY AND CONCLUSIONS

In this study analytical and empirical tests were performed using TARP. Because of the inherent complexity of TARP (and similar building energy analysis programs), it is difficult to really validate the entire program. Successful tests build confidence in the program; unsuccessful tests lead to corrections or improved algorithms.

TARP was found to be very accurate relative to the analytical tests. In the empirical tests TARP's predicted heating loads were generally near the estimated accuracy of the buildings' thermophysical properties. The prediction of cooling loads was less successful with an average difference from the measured loads of about 25%. Some of this difference is believed to be attributable to the uncertainty in the cooling loads measurements. The modeling of diffuse solar gains is considered to be a source of error.

Based on the tests described above, the following recommendations can be made:
1. There is a need for more extensive graphic output of the building description to help insure correct geometric input.
2. Algorithms for non-isotropic diffuse solar radiation and for automatic calculation of view factors between surfaces and the environment need to be implemented and tested.
3. Additional analytic and empirical tests would be useful. They could cover other important modes of heat transfer such as ground coupling, and other building configurations, particularly multi-room.
4. Analytic tests should be part of the information available on the TARP source code tape. This data should be used to verify that program modifications have not inadvertantly caused errors in other calculations.

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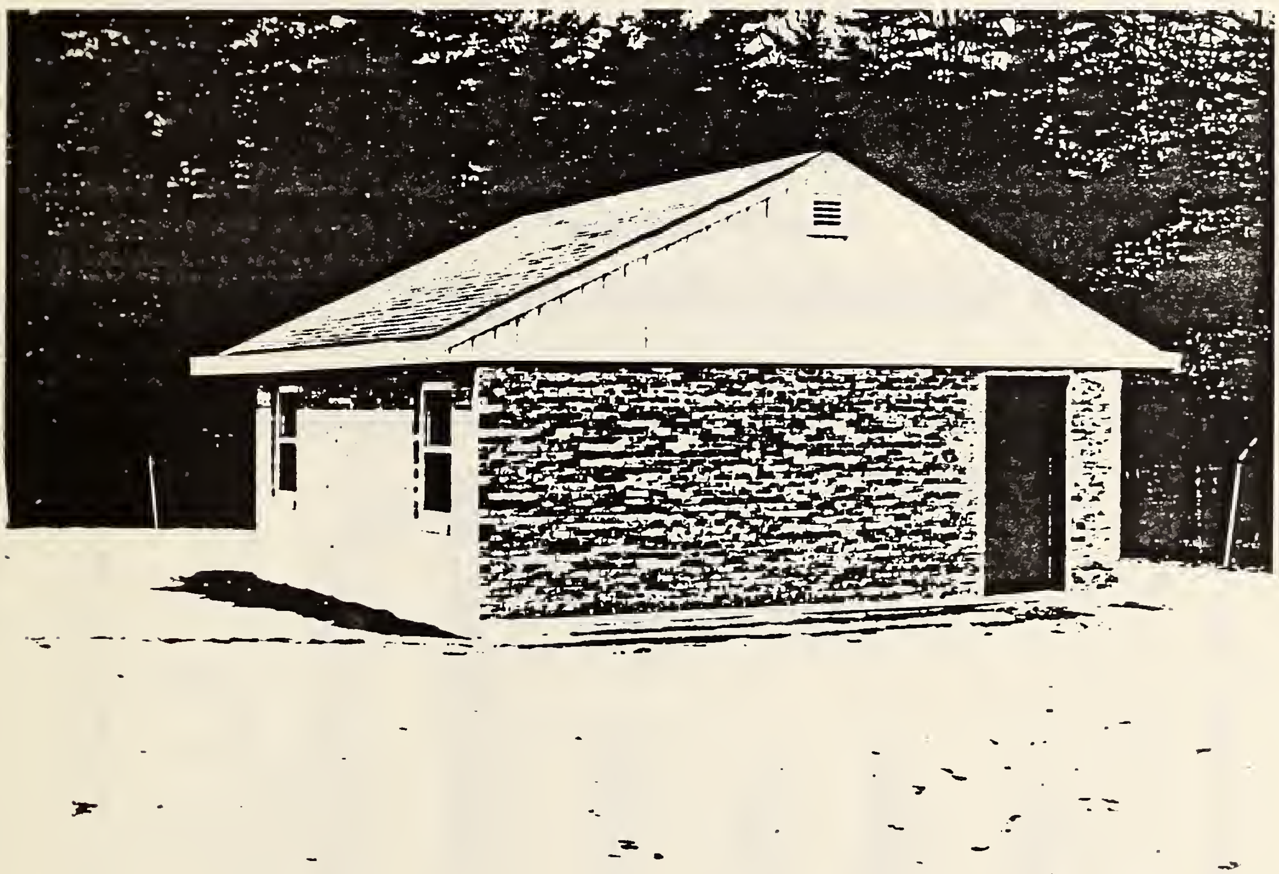

Figure 1. Photograph of one of the test buildings

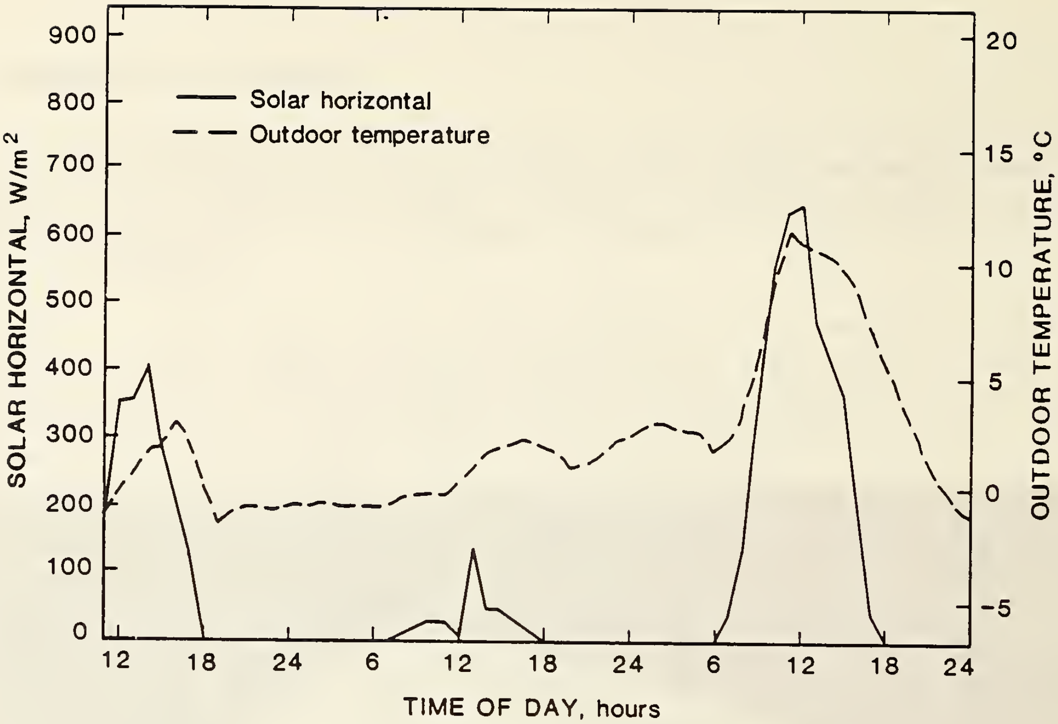

Figure 2. Outdoor weather during the winter test period

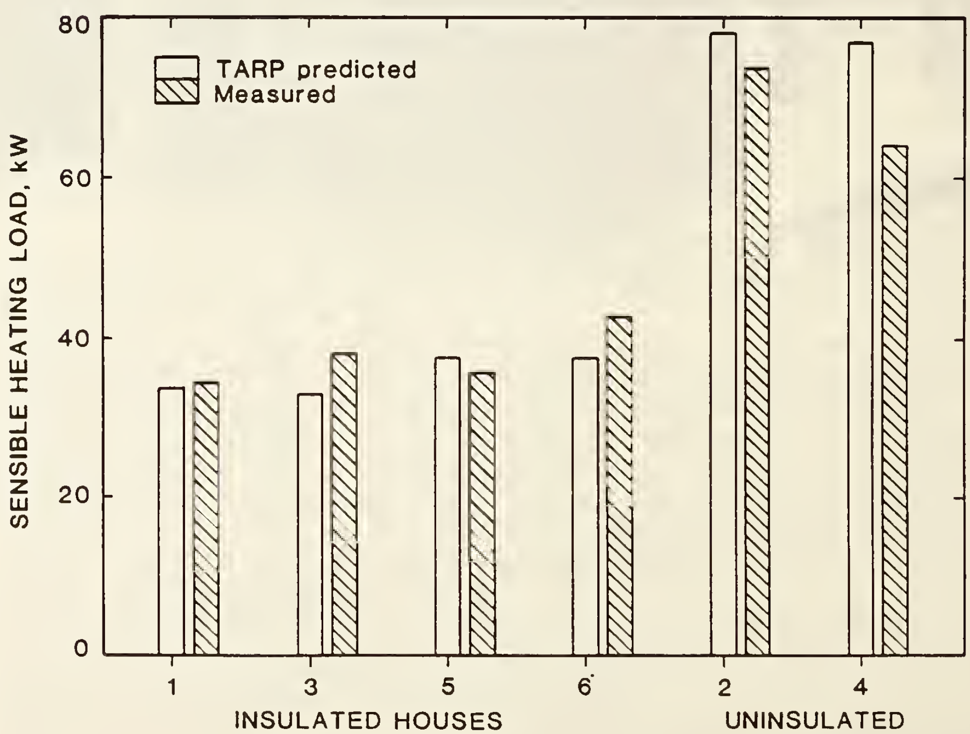

Figure 3. Comparison of measured and predict d cumulative heating loads for all six buildings for th winter test period

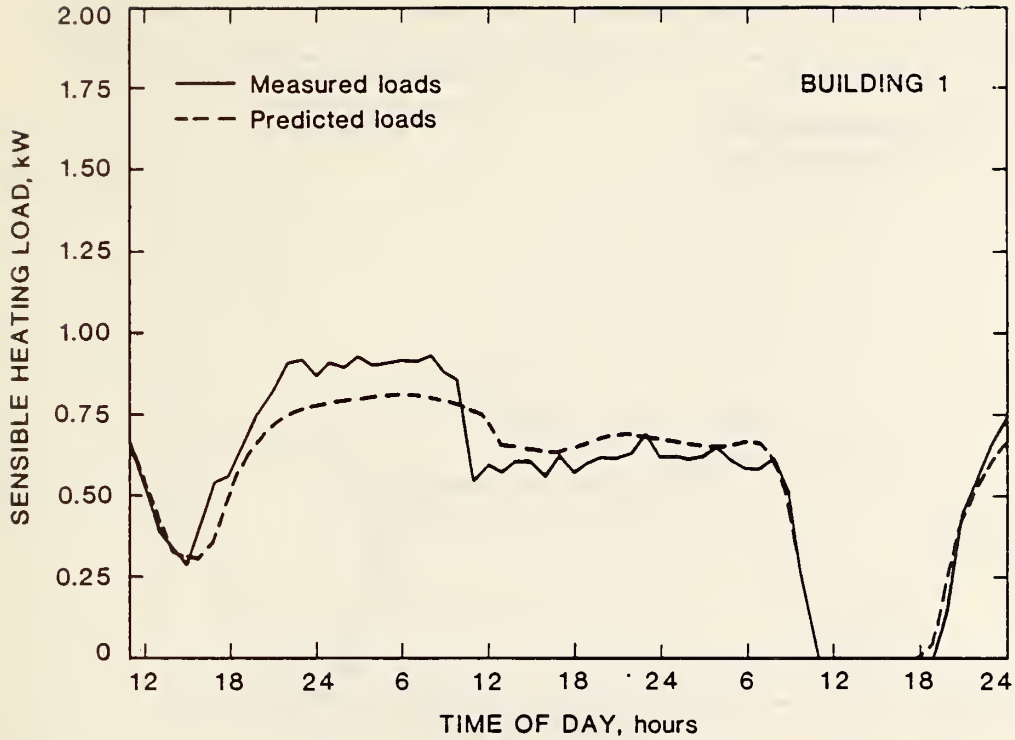

Figure 4. Comparison of measured and predicted heating loads for the insulated wood frame building for the winter test period

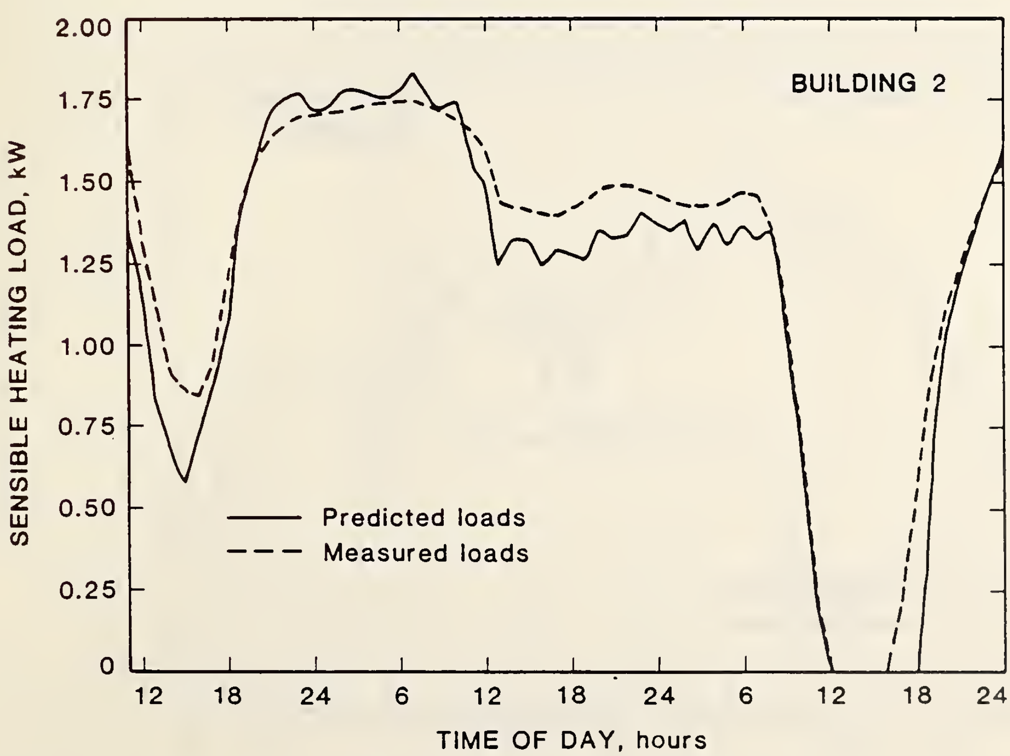

Figure 5. Comparison of measured and predicted heating loads for the uninsulated wood frame building for the winter test period

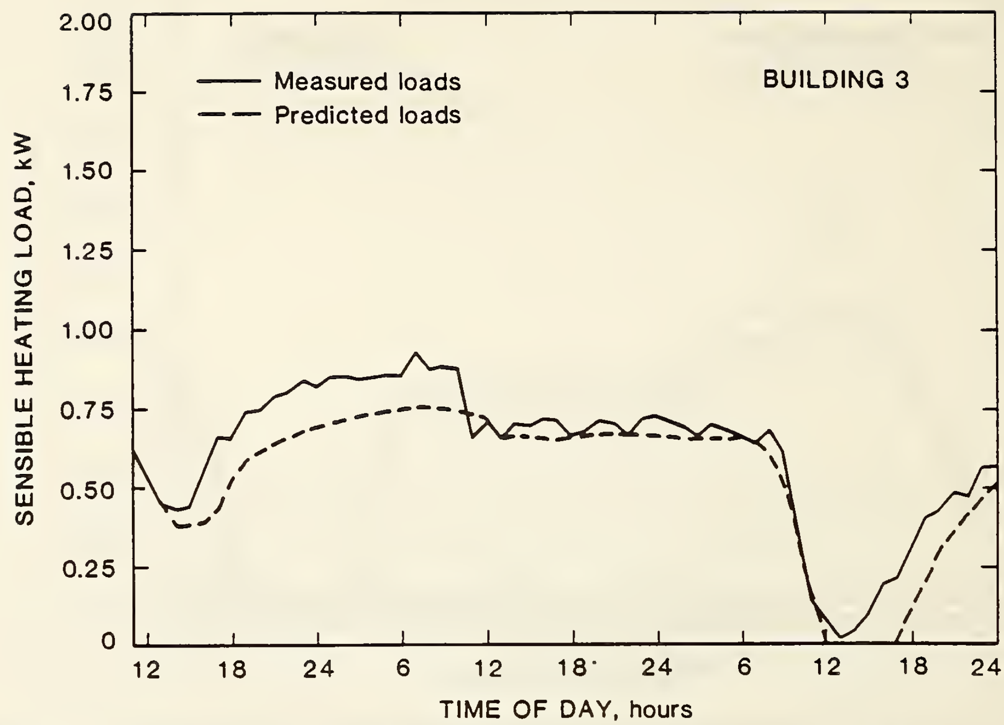

Figure 6. Comparison of measured and predicted heating loads for the insulated masonry building for the winter test period

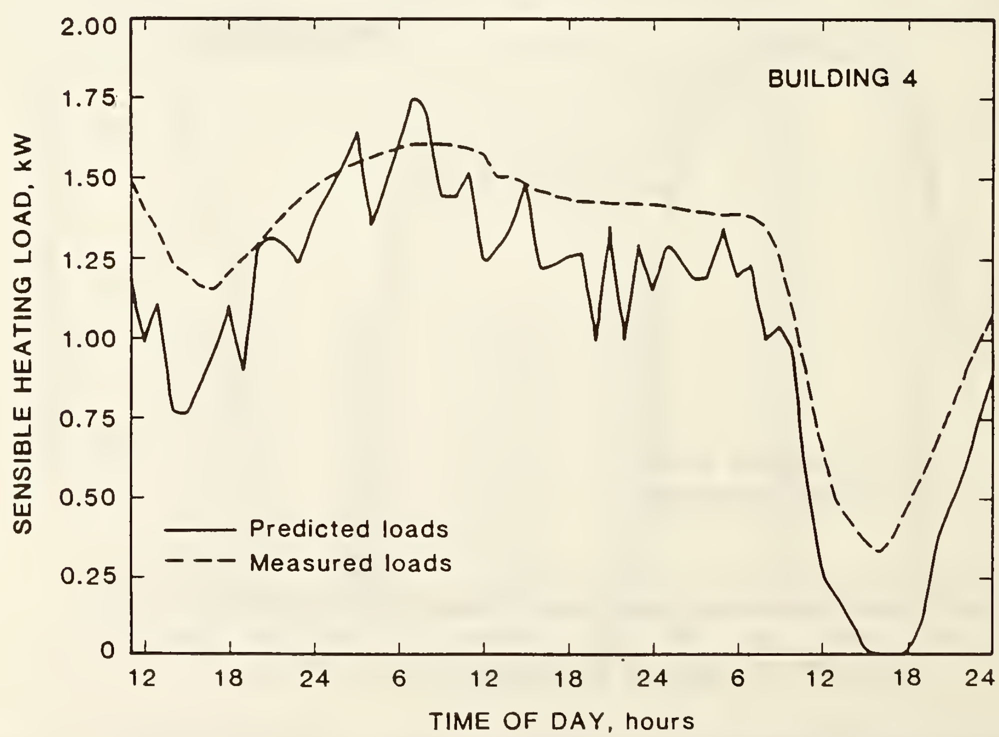

Figure 7. Comparison of measured and predicted heating loads for the uninsulated masonry building for the winter test period

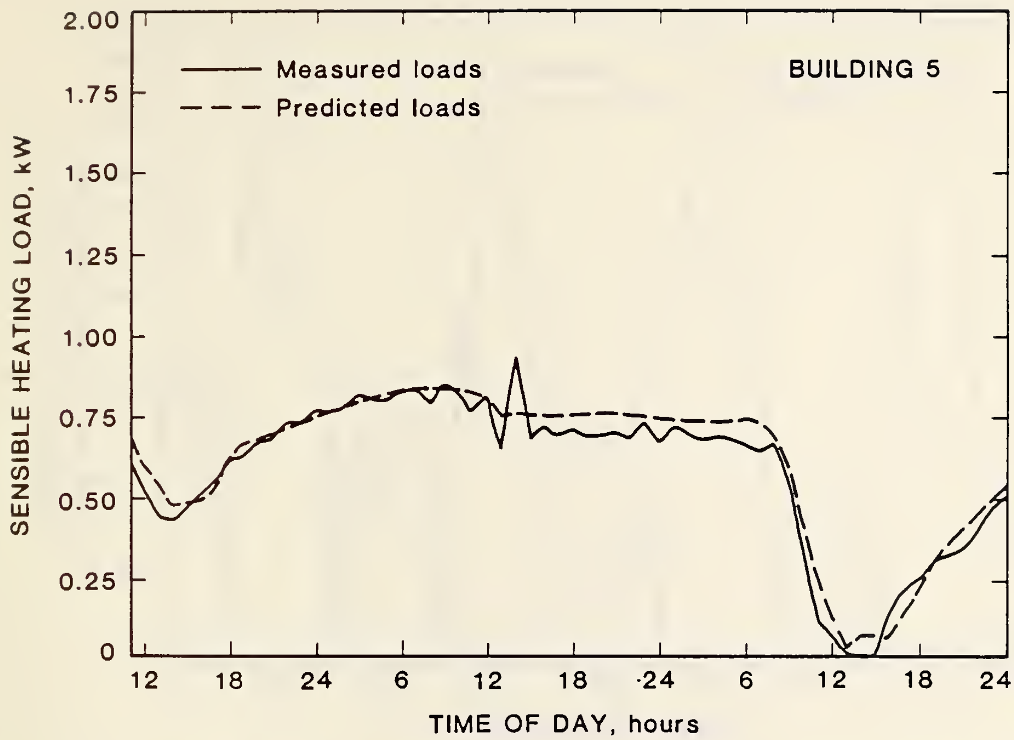

Figure 8. Comparison of measured and predicted heating loads for the log building for the winter test period.

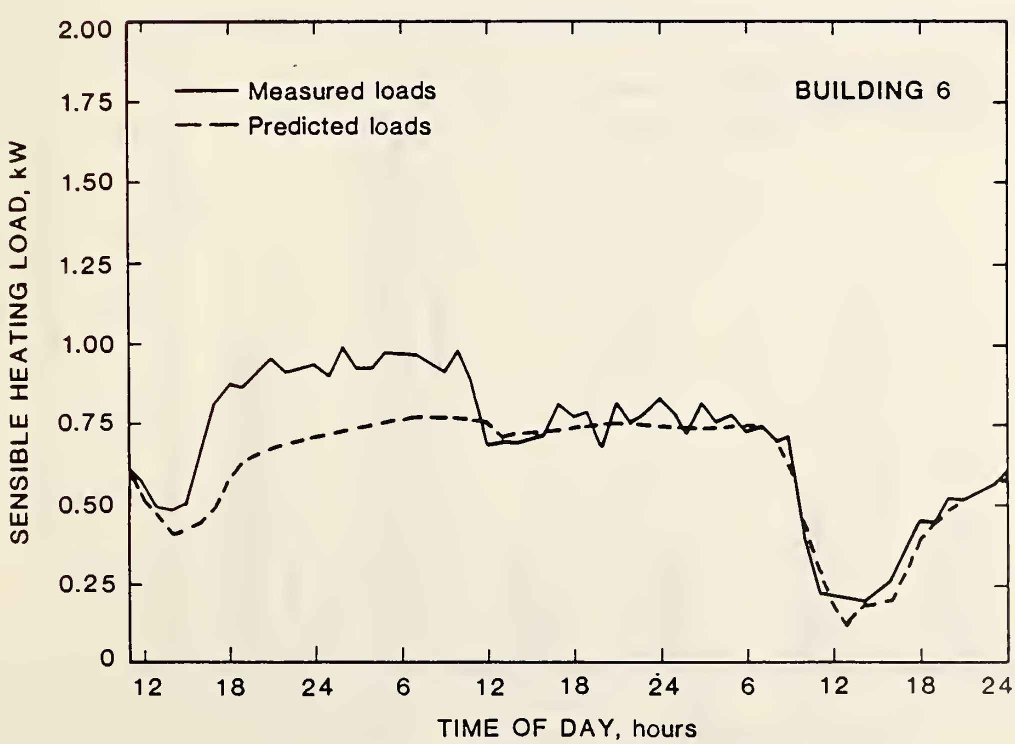

Figure 9. Comparison of measured and predicted heating loads for the inside mass masonry building for the winter test period

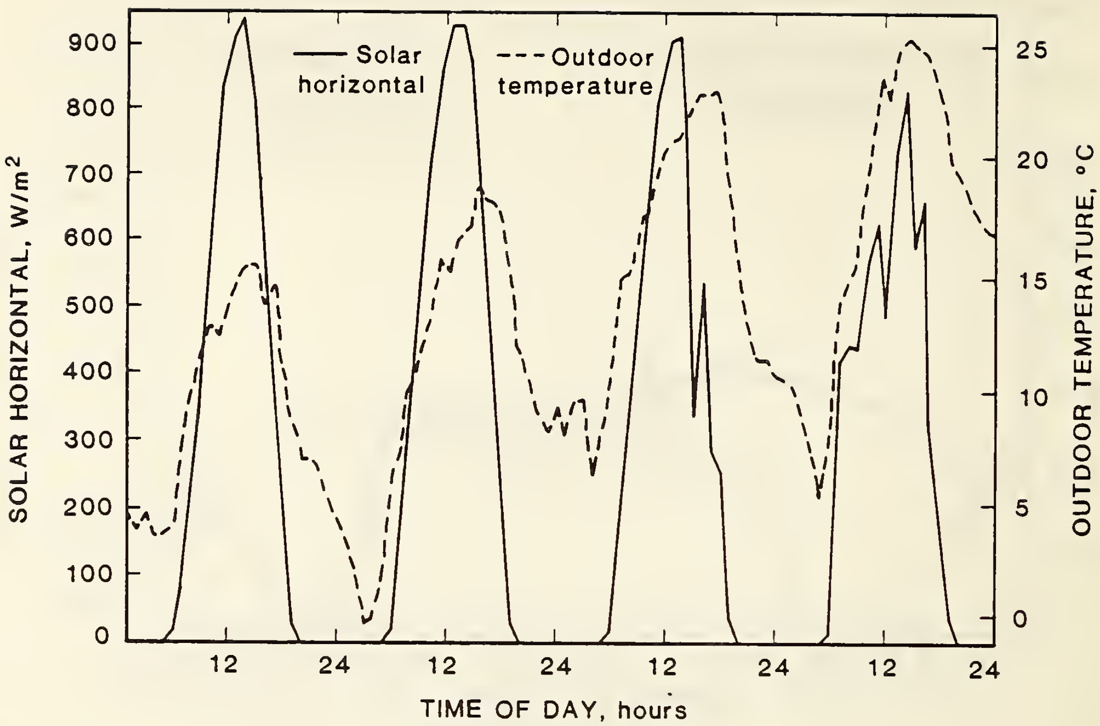

Figure 10. Outdoor weather during the spring test period

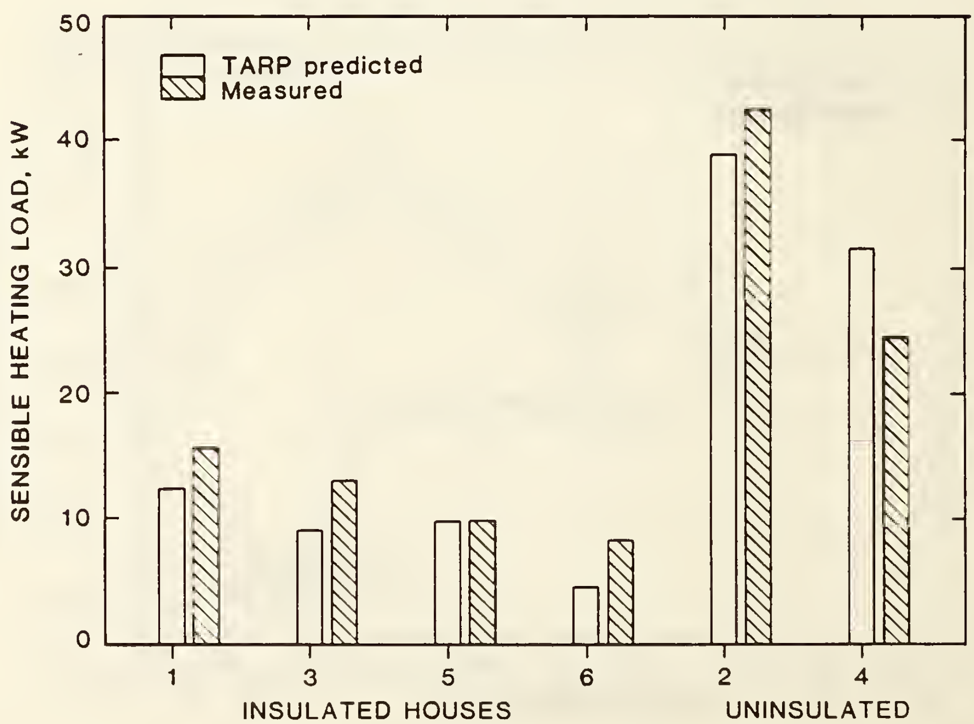

Figure 11. Comparison of measured and predicted cumulative heating loads for all six buildings for the spring test period

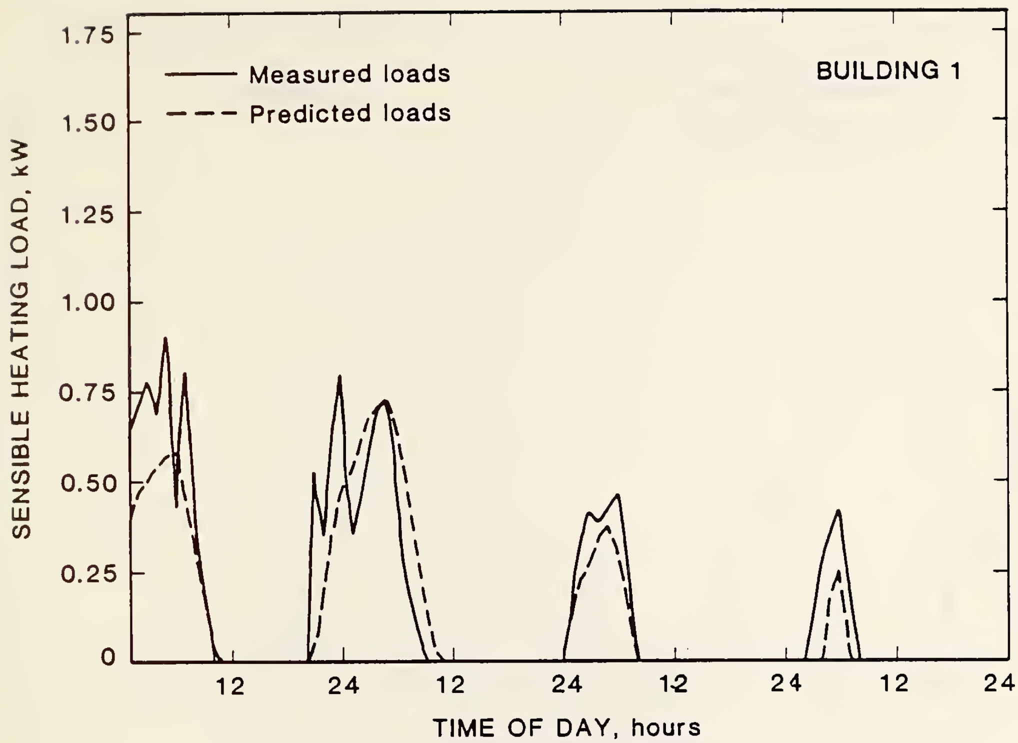

Figure 12. Comparison of measured and predicted heating loads for the insulated wood frame building for the spring test period

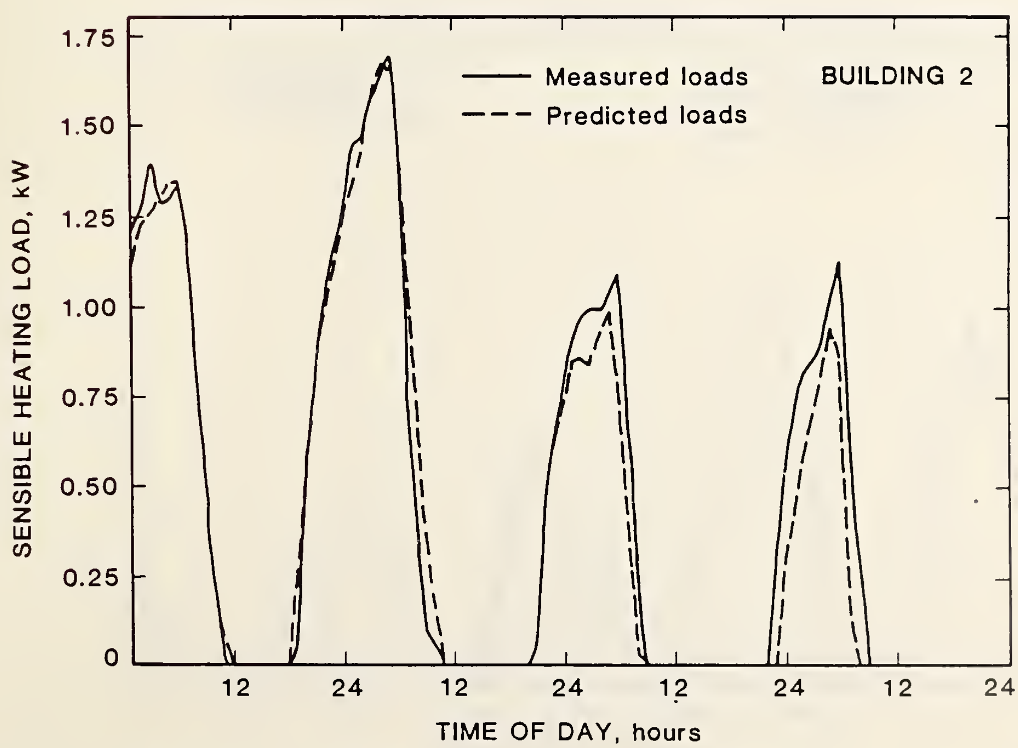

Figure 13. Comparison of measured and predicted heating loads for the uninsulated wood frame building for the spring test period

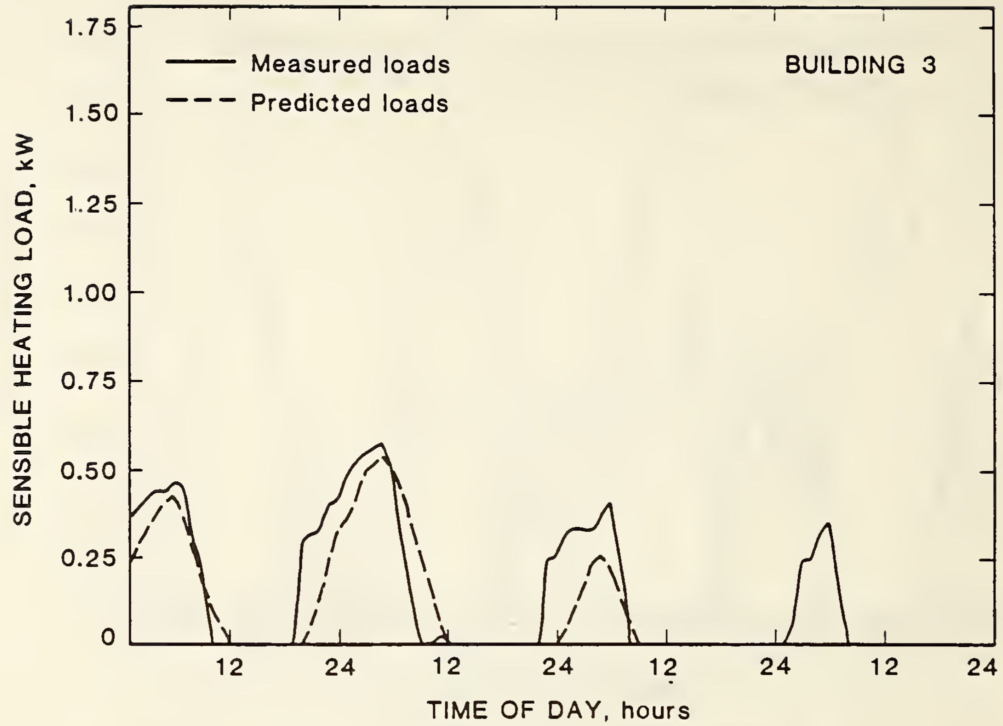

Figure 14. Comparison of measured and predicted heating loads for the insulated masonry building for the spring test period

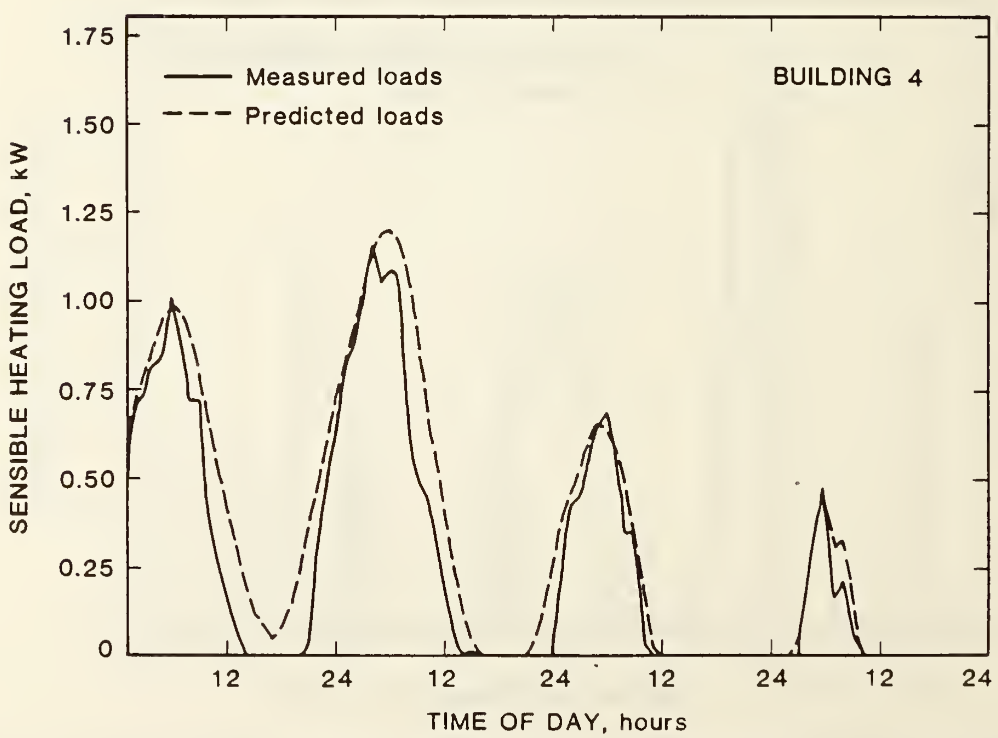

Figure 15. Comparison of measured and predicted heating loads for the uninsulated masonry building for the spring test period

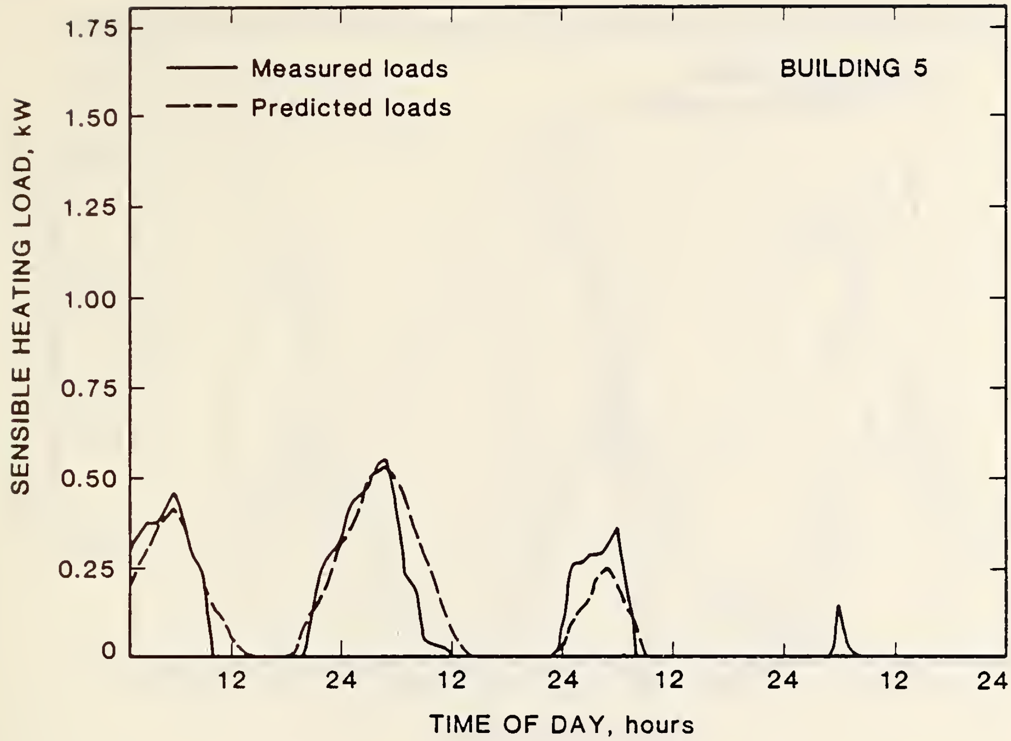

Figure 16. Comparison of measured and predicted heating loads for the log building for the spring test period.

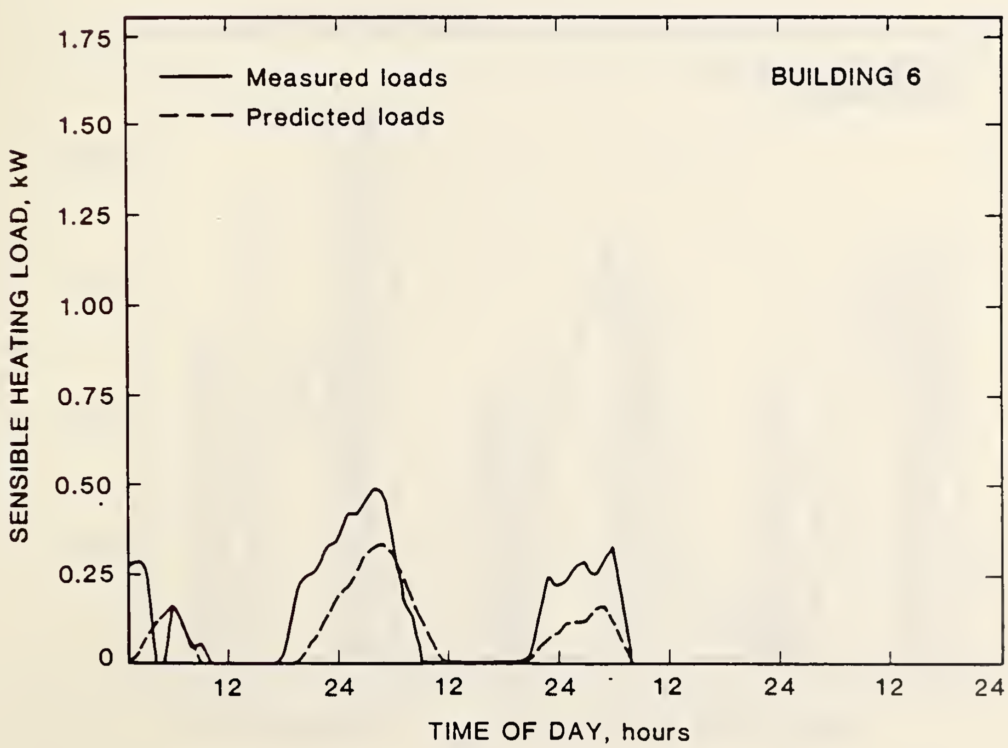

Figure 17. Comparison of measured and predicted heating loads for the inside mass masonry building for the spring test period

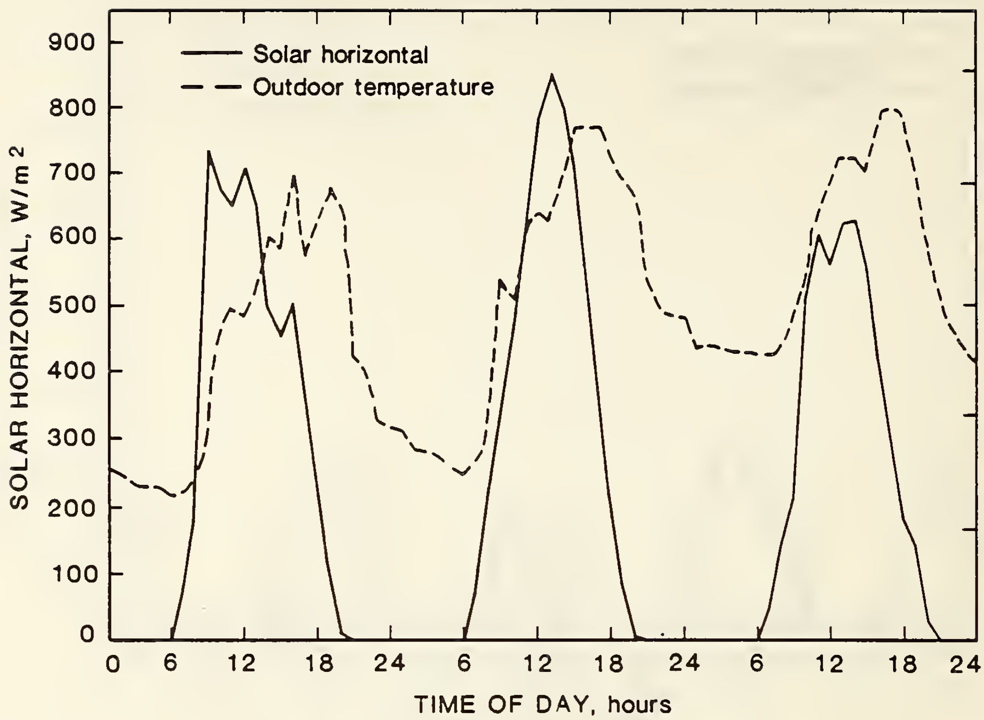

Figure 18. Outdoor weather during the s[illegible]mer test period

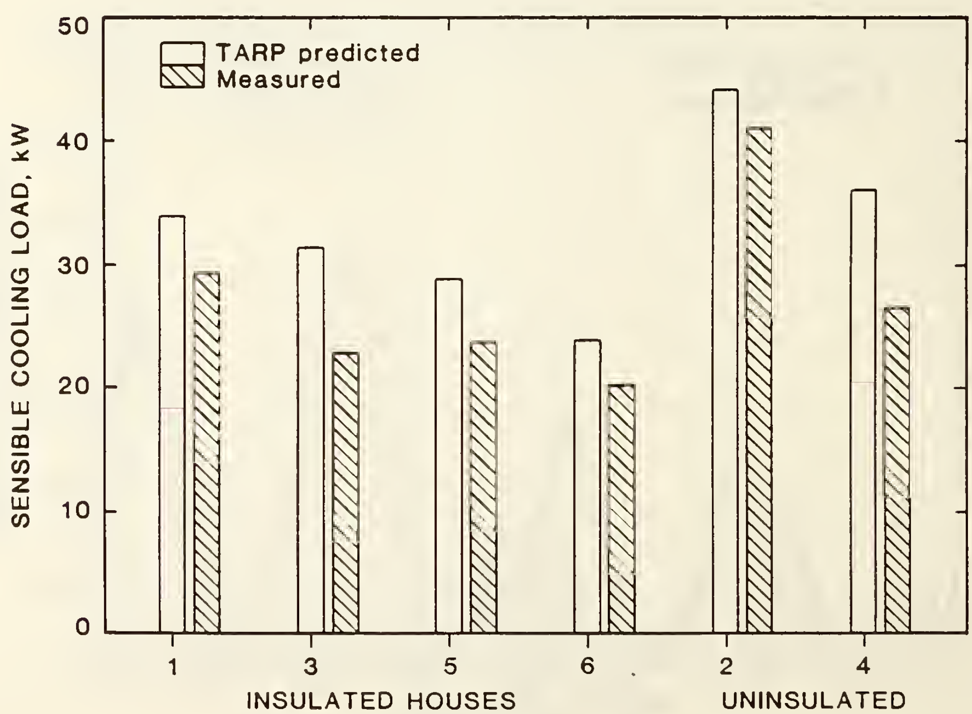

Figure 19. Comparison of measured and predicted cumulative cooling loads for all six buildings for the summer test period

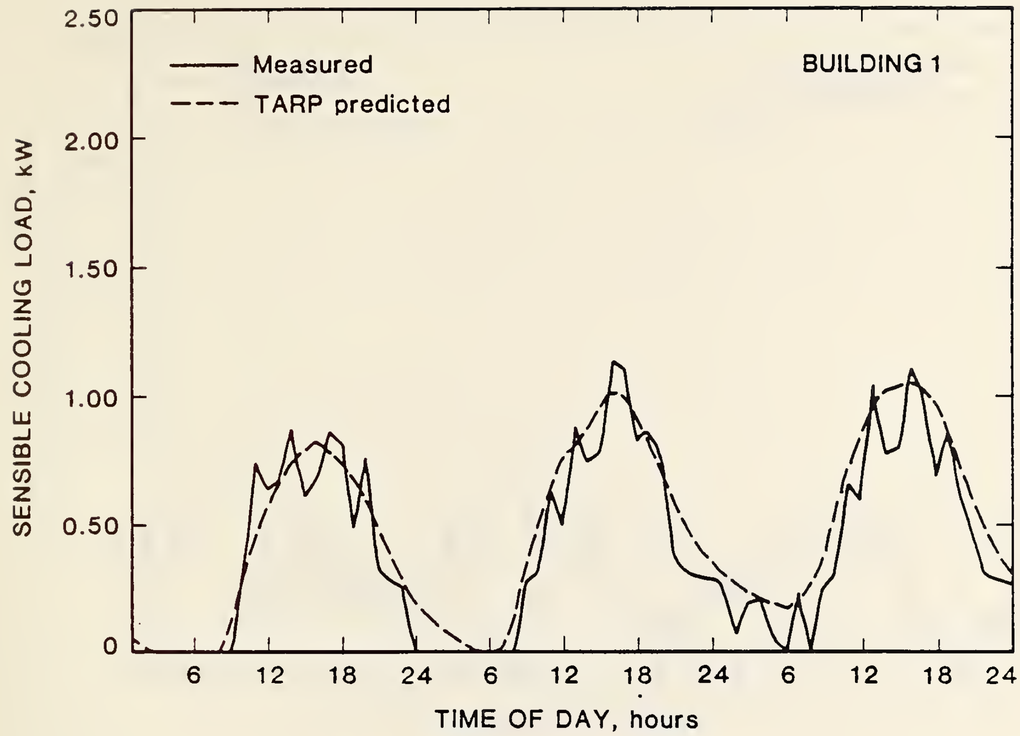

Figure 20. Comparison of measured and predicted cooling loads for the insulated wood frame building for the summer test period

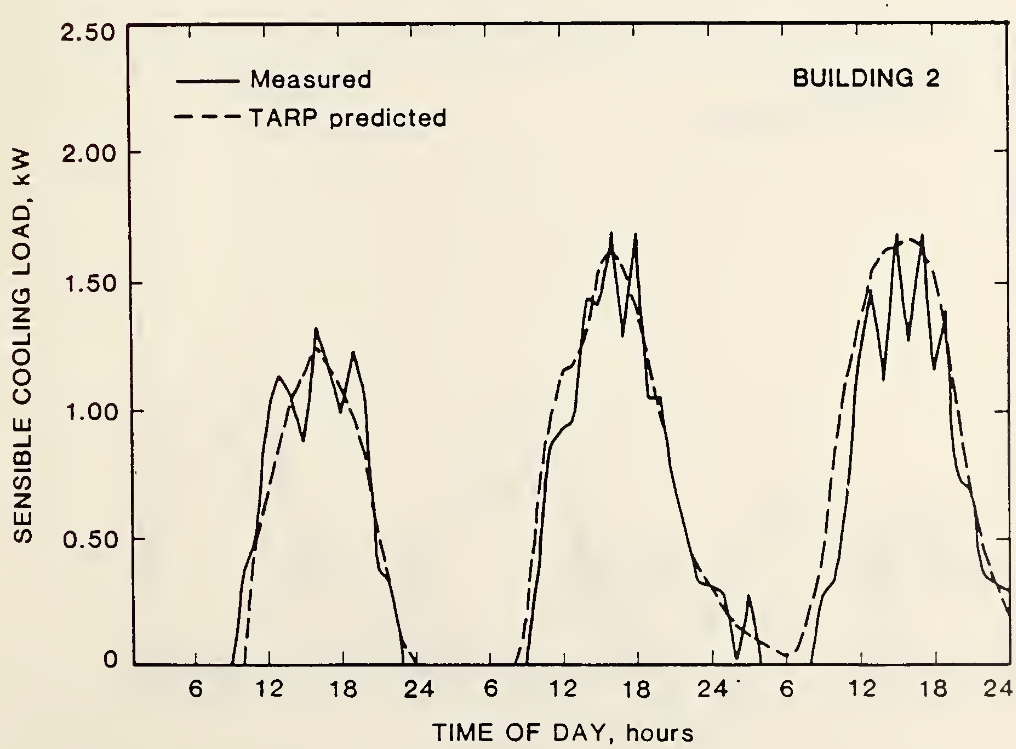

Figure 21. Comparison of measured and predicted cooling loads for the uninsulated wood frame building for the summer test period

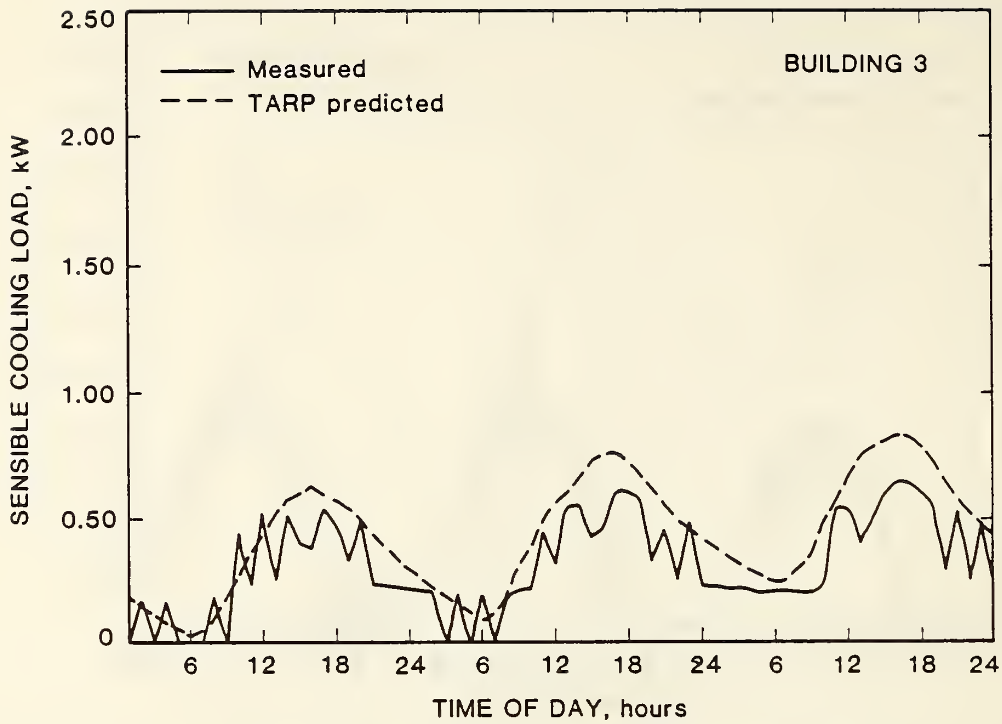

Figure 22. Comparison of measured and predicted cooling loads for the insulated masonry building for the summer test period

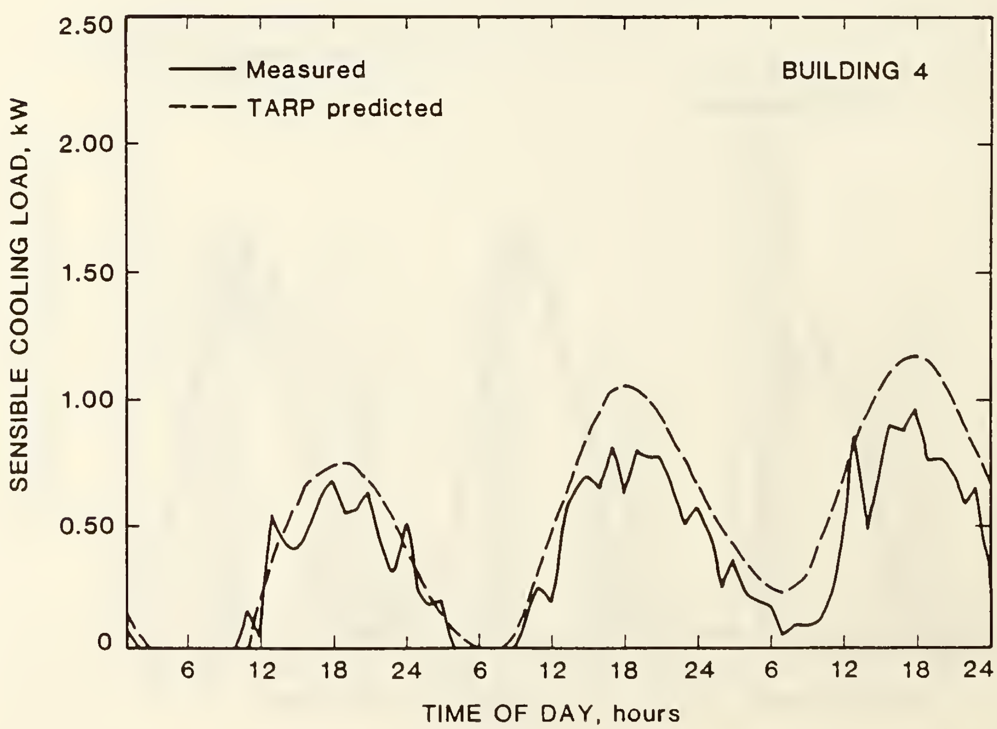

Figure 23. Comparison of measured and predicted cooling loads for the uninsulated masonry building for the summer test period

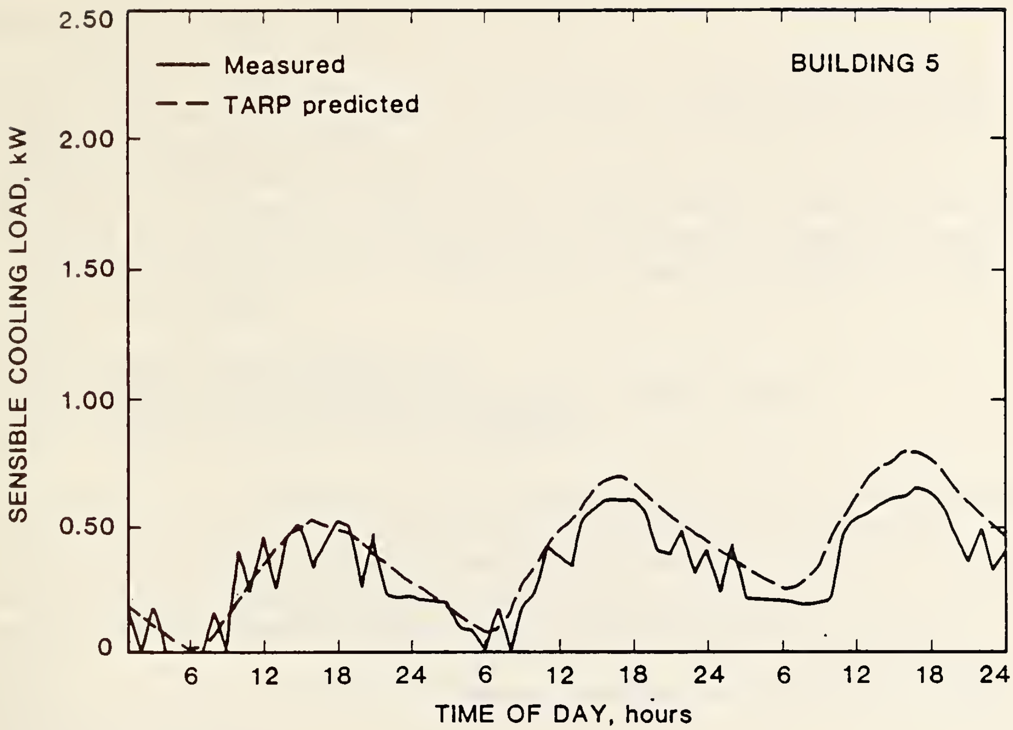

Figure 24. Comparison of measured and predicted cooling loads for the log building for the summer test period.

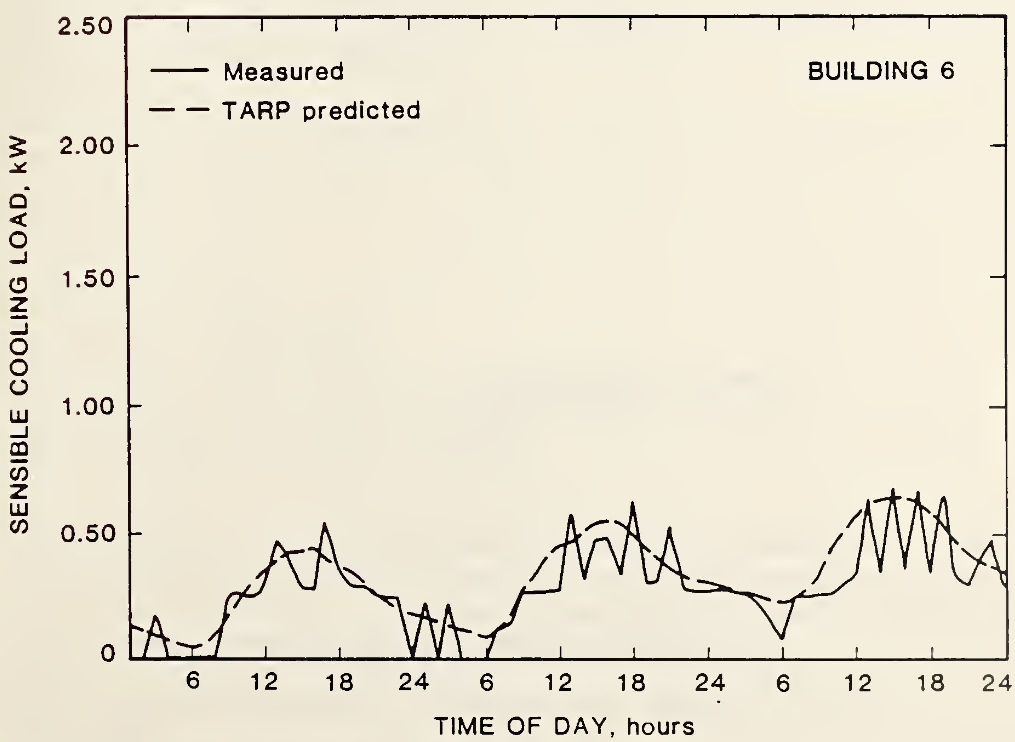

Figure 25. Comparison of measured and predicted cooling loads for the inside mass masonry building for the summer test period

APPENDIX A: TARP input for analytic tests

```
$   BDP-1   BDP input file for testing steady conduction and scheduled loads.
$   This file primarily tests keys 4.18, 4.3, 4.4, 4.5, and 4.6 .
$   This uses environment EFP-1.
$   Data will be converted from English units input to metric for the
$   simulation and back to English for the reports.  User defined reports
$   will be used extensively.  RNOS=8 will dump the contents of the simulation
$   input file (SINPFL).
PROJECT [
  RC(DEM/UIN=ENGLISH/UOUT=ENGLISH/
     DESC='STEADY CONDUCTION AND SCHEDULED LOADS TESTS')
  RPT(RNOS=8/HOURLY/DAILY/FINAL/WIDTH=80)
  ]
$   The library includes a set of schedules which are on during different
$   hours and are all on during the last three hours of the day.
$   The walls are described by R-valued materials so there is no mass effect
$   and no calculation of conduction transfer functions.  The zones will be
$   maintained at constant temperatures while heating or cooling.
LIBRARY [
$ LIB(ALL)                         $ Remove comment for detailed library reports.
  DS(NAME=C/FFC=24*1.0)
  WS(NAME=C/ALL=C)
  DS(NAME=C1/FFC=3*0,3*1,15*0,3*1)
  WS(NAME=C1/ALL=C1)
  DS(NAME=C2/FFC=6*0,3*1,12*0,3*1)
  WS(NAME=C2/ALL=C2)
  DS(NAME=C3/FFC=9*0,3*1,9*0,3*1)
  WS(NAME=C3/ALL=C3)
  DS(NAME=C4/FFC=12*0,3*1,6*0,3*1)
  WS(NAME=C4/ALL=C4)
  DS(NAME=C5/FFC=15*0,3*1,3*0,3*1)
  WS(NAME=C5/ALL=C5)
  DS(NAME=C6/FFC=18*0,3*1,3*1)
  WS(NAME=C6/ALL=C6)
  MATL(NAME=R10/R=10.0)
  MATL(NAME=R4/R=4.0)
  CONS(NAME=WALL10/MATL=0,R10)
  CONS(NAME=WALL4/MATL=0,R4)
  DS(NAME=HC/DESC='ZONE HEATING TEMPERATURES'/T=24*68.)
  DS(NAME=CC/DESC='ZONE COOLING TEMPERATURES'/T=24*78.)
  WS(NAME=HEAT/DESC='HEATING'/ALL=HC)
  WS(NAME=COOL/DESC='COOLING'/ALL=CC)
  ]
$   This simulation uses the simplest calculation procedures -- constant (user
$   defined) convection coefficients, radiant interchange combined with the
$   convection coefficient, no outside heat balance, and no geometry dependence.
$   It uses a very tight loads convergence criterion.
BUILDING [
  SIM(SLDS=0/HTB=0/RIM=0/HI=1,1.0/CNVG=.001,.000001,.01,12/
      RPT=TA,A /
      ZON=ZONE1,ZONE2,ZONE3,ZONE4/ SYS=LOADS)
  ]
```

```
$   The first zone, ZONE1, tests steady conduction simple walls
$   and known boundary conditions.  Each wall has an area of 1000 square feet.
$   The first wall has the outside temperature set to the air temperature by
$   the OSC (4.18.3).  The inside convection coefficient is the default giving
$   a total thermal conductance of .909 Btu/hsqftF.  The total heat loss
$   from by this wall is given by 1000 * .909 * (68. - TA) which ranges from
$   6000 Btu during the first hour to 1818.2 Btu during hour 24.
$   The second wall has a constant outside temperature of 48 F.  It has a
$   constant heat loss of (1000 * .909 * [68 - 48] =) 1818.2 Btu/h.
$   The third wall has a constant outside temperature of 43 F (the ground
$   temperature.  It also has a surface specific inside convection coefficient
$   (4.15.11) which gives a total thermal conductance of 0.0952.
$   The constant heat loss of this wall is 2381.0 Btu.
$   The fourth wall has a convection coefficient in the OSC (4.18.1).
$   The total thermal resistance of the wall is (1+10+1=) 12.  The heat loss
$   of wall 4 ranges from 5500. Btu during hour 1 to 1666.7 Btu during hour 24.
$   The expected hourly heating loads for ZONE1 are:
$   hours 1-6       15700.1   15351.6   15003.1   14654.6   14306.2   13957.7
$   hours 7-12      13609.2   13260.7   12912.2   12563.7   12215.3   11866.8
$   hours 13-18     11518.3   11169.8   10821.3   10472.8   10124.4    9775.9
$   hours 19-24      9427.4    9078.9    8730.4    8381.9    8033.5    7685.0
ZONE [
  GEOM(NAME=ZONE1/VOL=0.01/RPT=HLS,T)
  SRF(EX/OP/BS/CONS=WALL10/AZM=0/ORG=100,100,0/SIZE=100,10)
    OSC(TAP=1)
  SRF(EX/OP/BS/CONS=WALL10/AZM=90/ORG=100,0,0/SIZE=100,10)
    OSC(CT=48/CTP=1)
  SRF(EX/OP/BS/CONS=WALL10/HC=2.0/AZM=180/ORG=0,0,0/SIZE=100,10)
    OSC(TGP=1)
  SRF(EX/OP/BS/CONS=WALL10/AZM=270/ORG=0,100,0/SIZE=100,10)
    OSC(HO=1.0/TAP=1)
  ]
$   The second zone, ZONE2, tests the scheduling of convective internal gains
$   from lights, equipment, and simple infiltration.  The two walls have a
$   heat gain of 3636.4 Btu/h.  This is augmented by convective gains from
$   lights and equipment.  These gains are scheduled to occur during different
$   hours to test hourly scheduling and have different energy sources to test
$   the user defined zone reports.  They also occur simultaneously
$   during the last three hours of the day.
$   These heat gains are offset by infiltration which is estimated by
$   1.08 * CFM * (78 - TA).  This ranges from 820.8 Btu during hour 1 to
$   324.0 Btu during hour 24.
$   The expected hourly cooling loads for ZONE2 are:
$   hours 1-6       2815.6    2837.2    2858.8    2980.4    3002.0    3023.6
$   hours 7-12      3045.2    3066.8    3088.4    3110.0    3131.6    3153.2
$   hours 13-18     3174.8    3196.4    3218.0    3239.6    3261.2    3282.8
$   hours 19-24     3304.4    3326.0    3247.6    3869.2    3890.8    3912.4
ZONE [
  GEOM(NAME=ZONE2/VOL=0.01/RPT=CLS,T,ELZ,T,GSZ,T,STZ,T,HWZ,T,OTZ,T)
  SRF(EX/OP/BS/CONS=WALL10/AZM=0/ORG=10,10,0/SIZE=100,10)
    OSC(CT=98./CTP=1)
  SRF(EX/OP/BS/CONS=WALL10/AZM=180/ORG=0,0,0/SIZE=100,10)
    OSC(CT=98./CTP=1)
  LIT(WS=C1/CAP=.1/RA=0/RAD=0/VIS=0/REP=0)
```

```
  EQP(WS=C2/CAP=.1/LAT=0/RAD=0/LOST=0/EL)
  EQP(WS=C3/CAP=.1/LAT=0/RAD=0/LOST=0/GS)
  EQP(WS=C4/CAP=.1/LAT=0/RAD=0/LOST=0/ST)
  EQP(WS=C5/CAP=.1/LAT=0/RAD=0/LOST=0/HW)
  EQP(WS=C6/CAP=.1/LAT=0/RAD=0/LOST=0/OTHR)
  INF(WS=C/CAP=10./C=1/T=0/V=0/VV=0)
  ]
$   The third zone, ZONE3, tests the baseboard heat algorithm (4.12).
$   The two walls have a heat loss which ranges from 6000. Btu at hour 1 to
$   1818.2 Btu at hour 24.  This heat loss is offset by basebaord heat of
$   4000. Btu when TA <= 20 F to 2000. Btu when TA = 40F and zero when TA > 40.
$   The expected hourly heating loads for ZONE3 are:
$   hours 1-6       2000.0    1818.2    1636.4    1454.5    1272.7    1090.9
$   hours 7-12       909.1     727.3     545.5     363.6     381.8     400.0
$   hours 13-18      418.2     436.4     454.5     472.7     490.9     509.1
$   hours 19-24      527.5     545.5    2363.6    2181.8    2000.0    1818.2
ZONE [
  GEOM(NAME=ZONE3/VOL=0.01/RPT=HLS,T)
  BBH(WS=C/CAP=4.,2./TMP=20,40/RAD=0/ST)
  SRF(EX/OP/BS/CONS=WALL10/AZM=0/ORG=50,50,0/SIZE=50,10)
    OSC(TAP=1)
  SRF(EX/OP/BS/CONS=WALL10/AZM=180/ORG=0,0,0/SIZE=50,10)
    OSC(TAP=1)
  ]
$   The fourth zone, ZONE4, tests the non-convective gains from sheduled loads.
$   The single wall (possible only with RIM=0 (3.1.8)) has a heat loss
$   of 13200. Btu.  This loss is offset by various scheduled gains.
$   After radiant energy is absorbed by a wall, part of it is convected back
$   into the room air to become part of the zone load and part of it is
$   conducted to the outside.  For the combination of thermal resistances in
$   ZONE4, 20% [=1/(1+4)] of the radiant energy is lost to the outside.
$   The expected hourly heating loads for ZONE4 are:
$   hours 1-6      13200.0   13200.0   13200.    12200.0   12200.0   12200.0
$   hours 7-12     12320.0   12320.0   12320.0   12720.0   12720.0   12720.0
$   hours 13-18    12200.0   12200.0   12200.0   12380.0   12380.0   12380.0
$   hours 19-24    12480.0   12480.0   12480.0    8300.0    8300.0    8300.0
ZONE [
  GEOM(NAME=ZONE4/VOL=0.01/RPT=HLS,T)
  SRF(EX/OP/BS/CONS=WALL4/AZM=180/ORG=0,0,0/SIZE=100,10)
    OSC(CT=2/CTP=1)
  EQP(WS=C1/CAP=1./LAT=0/RAD=0/LOST=0/GS)
  EQP(WS=C2/CAP=1./LAT=0/RAD=.6/LOST=0/GS)
  EQP(WS=C3/CAP=1./LAT=.2/RAD=.6/LOST=.2/GS)
  LIT(WS=C4/CAP=1./RA=0/RAD=0/VIS=0/REP=0)
  LIT(WS=C5/CAP=1./RA=0/RAD=.8/VIS=.1/REP=0)
  LIT(WS=C6/CAP=1./RA=.2/RAD=.2/VIS=.2/REP=0)
  ]
SYSTEM [
  SYS(NAME=LOADS)
  DES(ZONE=ZONE1/HTWS=HEAT/CLWS=COOL)
  DES(ZONE=ZONE2/HTWS=HEAT/CLWS=COOL)
  DES(ZONE=ZONE3/HTWS=HEAT/CLWS=COOL)
  DES(ZONE=ZONE4/HTWS=HEAT/CLWS=COOL)
  ]
```

```
$   BDP-2   BDP input file for testing transient conduction calculations.
$   This uses environment EFP-2.
$
$   The use of conduction transfer functions (CTF) to calculate transient
$   conduction is tested by comparing the temperature of a wall, as it responds
$   to a step change in air temparature, to an analytic solution.
$   User defined reports print the appropriate wall and air temperatures.
PROJECT [
  RC(DEM/UIN=ENGLISH/UOUT=ENGLISH/DESC='TRANSIENT CONDUCTION TESTS')
  RPT(HOURLY/FROM=28FEB/THRU=6MAR)
$ RPT(HOURLY/FROM=30APR/THRU=6MAY)     $ Use this alternative to report T decay.
  ]
$   Control schedules are set up to create step changes in the zone air
$   temperature for zones 1 and 2.  Zone 6 is maintained at a constant
$   temperature.
$   Several different wall constructions are tested.
$   WALL1A and WALL1B are one foot thick sections of a generic masonry
$   material.  There are one layer and three layer versions of this wall
$   because TARP uses slightly different techniques to compute the CTF
$   of one and multi-layered walls.  The library report will show if
$   exactly the same CTF coefficients are computed for both.
$   WALL2A and WALL2B are 0.1 foot thick walls of the same material.
$   Thin walls have very few CTF coefficients.
$   LOWMASS, MEDMASS, and HIMASS are two-layer walls which can also be
$   tested against the analytic solution.
LIBRARY  [
  LIB(CONS)
  DS(NAME=H90/DESC='ZONE HEATING TEMPERATURES'/T=24*90)
  DS(NAME=C40/DESC='ZONE COOLING TEMPERATURES'/T=24*40)
  DS(NAME=S65/DESC='ZONE COOLING TEMPERATURES'/T=24*65)
  WS(NAME=HEAT90/DESC='HEATING'/ALL=H90)
  WS(NAME=COOL40/DESC='COOLING'/ALL=C40)
  WS(NAME=SET65/DESC='COOLING'/ALL=S65)
  MATL(NAME=M1/K=0.75/D=120./CP=0.2)
  MATL(NAME=GYP-BOARD/K=.25/D=78/CP=.26)
  MATL(NAME=CONCRETE/K=.54/D=144/CP=.16)
  MATL(NAME=RLOW/R=12.783)
  MATL(NAME=RMED/R=12.332)
  MATL(NAME=RHI/R=11.872)
  CONS(NAME=WALL1A/MATL=1.0,M1)
  CONS(NAME=WALL1B/MATL=0.25,M1, 0.25,M1, 0.50,M1)
  CONS(NAME=WALL2A/MATL=0.1,M1)
  CONS(NAME=WALL2B/MATL=0.05,M1, 0.05,M1)
  CONS(NAME=LOWMASS/MATL=0,RLOW, .0416667,GYP-BOARD)
  CONS(NAME=MEDMASS/MATL=0,RMED, .333333,CONCRETE)
  CONS(NAME=HIMASS /MATL=0,RHI,  .583333,CONCRETE)
  ]
$   Very tight limits are used for loads convergence.  Known, constant
$   convection coefficients are needed for comparison to the analytic solution.
BUILDING [
  SIM(SLDS=0/HTB=0/CNVG=.00001,.000001,.010,24/HO=1,4./HI=1,1./
      RPT=TA,I/
      ZON=ZONE1,ZONE2,ZONE3,ZONE4,ZONE5,ZONE6/ SYS=LOADS)
  ]
```

```
$   The solution of the analytic test is presented in most heat transfer
$   texts (e.g. Eckert & Drake, Analysis of Heat and Mass Transfer, 1972,
$   McGraw-Hill, Inc., pp 143-147).  The problem consists of a flat plate
$   of thickness 2L in the x-direction and infinite extent in the y- and
$   z-directions.  This plate is initially at a uniform temperature equal
$   to the temperature of the surrounding fluid (air).  At time zero,
$   there is an instantaneous change in the air temperature.  This is
$   transferred to or from the slab through a convection coefficient
$   causing the temperature of the slab to change as a function of time
$   and position in the slab.  This configuration is also equivalent to
$   a slab of thickness L which is insulated on one side.
$   The conduction transfer function method in TARP (and most other building
$   energy analysis programs)  cannot exactly represent a step change in
$   temperature because triangular pulses are used in generating the CTF.
$   All temperatures are assumed to change linearly from time t to time
$   t + delta.  In TARP delta is a one hour timestep.  The TARP solution
$   at time t + n*delta should lie between the analytic solutions for time
$   t + (n-1)*delta and time t + n*delta.
$   Zones 1 and 2 use the internal partition (IN/OP/BS) and equivalent MASS
$   configurations for cases which can be compared to the analytic solution.
$   The system control strategy changes the room air temperature.  The
$   temperatures of all four surfaces should be identical and equal to
$   the mean radiant temperature (TR) which is reported for comparison
$   to the analytic solution for the surface temperature (at x=L).
$   The normalized temperature of the surface is defined as
$         TN = (TI - TZ)/(TI0 - TZ)
$   Where
$         TI = wall surface temperature,
$         TZ = room air temperature,
$         TI0 = initial surface temperature.
$   The following table gives the limits of the expected normalized
$   temperature when TI is rising and the temperatures (degrees F) when they
$   are rising (T+) and when they are falling (T-) for WALL1A or B:
$   time    TNmin    TNmax          T+min    T+max          T-max    T-min
$    0      0.000    0.000          40.0     40.0           90.0     90.0
$    1      0.000    0.2189         40.0     50.946         90.0     79.054
$    2      0.2189   0.2888         50.946   54.438         79.054   75.562
$    3      0.2888   0.3399         54.438   56.996         75.562   73.004
$    4      0.3399   0.3843         56.996   59.214         73.004   70.786
$    8      0.4626   0.4978         63.130   64.890         66.870   65.110
$   12      0.5901   0.6170         69.506   70.848         60.494   59.152
$   16      0.6874   0.7078         74.369   75.392         55.631   54.608
$   20      0.7616   0.7772         78.078   78.858         51.922   51.142
$   24      0.8181   0.8300         80.906   81.502         49.094   48.498
$   28      0.8613   0.8704         83.064   83.518         46.936   46.482
$   32      0.8942   0.9011         84.710   85.056         45.290   44.944
$   36      0.9193   0.9246         85.965   86.229         44.035   43.770
ZONE [
  GEOM(NAME=ZONE1/VOL=.01/RPT=TR,I)
  SRF(IN/OP/BS/CONS=WALL1A/AZM=0/ORG=10,10,0/SIZE=10,10)
  SRF(IN/OP/BS/CONS=WALL1B/AZM=0/ORG=10,10,0/SIZE=10,10)
  MASS(CONS=WALL1A/AREA=100)
  MASS(CONS=WALL1B/AREA=100)
  ]
```

```
$   The response of ZONE2 should be compared to the following values
$   for WALL2A or B:
$   time    TNmin   TNmax         T+min   T+max          T-max   T-min
$    0      0.000   0.000         40.0    40.0           90.0    90.0
$    1      0.000   0.5671        40.0    68.356         90.0    61.644
$    2      0.5671  0.8084        68.356  80.421         61.644  49.579
$    3      0.8084  0.9152        80.421  85.760         49.579  44.240
$    4      0.9152  0.9625        85.760  88.124         44.240  41.876
$    5      0.9625  0.9834        88.124  89.200         41.876  40.800
$    6      0.9834  0.9926        89.200  89.632         40.800  40.368
ZONE [
  GEOM(NAME=ZONE2/VOL=.01/RPT=TR,I)
  SRF(IN/OP/BS/CONS=WALL2A/AZM=0/ORG=10,10,0/SIZE=10,10)
  SRF(IN/OP/BS/CONS=WALL2B/AZM=0/ORG=10,10,0/SIZE=10,10)
  MASS(CONS=WALL2A/AREA=100)
  MASS(CONS=WALL2B/AREA=100)
  ]
$   Zones 3 through 5 follow the transient conduction test developed at the
$   Solar Energy Research Institute (Judkoff, Wortman, O'Doherty, & Burch,
$   "A Methodology for Validating Building Energy Analysis Simulations",
$   SERI/TR-254-1508, August 1983).
$   Walls consist of a massive part on the inside and a massless part outside.
$   The same mathematical analysis is performed as for zones 1 and 2 with the
$   massless layer combined with the outside convection coefficient.  The inside
$   surfaces of all walls of a zone are at the same temperature which equals
$   the zone air temperature.  This should equal the centerline temperature
$   of the massive slab.  Solutions for three levels of mass are presented.
$   Values of the normalized temperature, TN, have been independently
$   computed and are presented along with the SERI values.  There are small
$   differences in the values which may be due to different accuracies in
$   evaluating the eigenvalues and series summations.  The following table
$   gives the limits of the expected normalized temperature, the temperatures
$   (degrees F) when they are rising and when they are falling, and the
$   SERI values for TN for the low mass wall:
$   time   TNmin   TNmax       T+min   T+max       T-max   T-min     TN(SERI)
$    0     0.000   0.000       40.0    40.0        90.0    90.0       0.000
$    1     0.000   0.0845      40.0    44.226      90.0    85.774     0.086
$    2     0.0845  0.1637      44.226  48.183      85.774  81.817     0.165
$    3     0.1637  0.2360      48.183  51.798      81.817  78.202     0.237
$    4     0.2360  0.3020      51.798  55.101      78.202  74.899     0.303
$    5     0.3020  0.3624      55.101  58.118      74.899  71.882     0.363
$    6     0.3624  0.4175      58.118  60.874      71.882  69.126     0.418
$    7     0.4175  0.4678      60.874  63.392      69.126  66.608     0.468
$    8     0.4678  0.5138      63.392  65.692      66.608  64.308     0.514
$   12     0.6294  0.6614      71.468  73.070      58.532  56.930       -
$   16     0.7418  0.7642      77.092  78.208      52.908  51.792       -
$   20     0.8202  0.8357      81.010  81.786      48.990  48.214       -
$   24     0.8748  0.8856      83.738  84.280      46.262  45.720       -
```

```
ZONE [
  GEOM(NAME=ZONE3/RPT=TZ,I/VOL=.01/PLAN=-5,35,-5,10)
  SRF(EX/OP/BS/CONS=LOWMASS/AZM=0/ORG=30,5,0/SIZE=30,8)
  SRF(EX/OP/BS/CONS=LOWMASS/AZM=90/ORG=30,0,0/SIZE=5,8)
  SRF(EX/OP/BS/CONS=LOWMASS/AZM=180/ORG=0,0,0/SIZE=30,8)
  SRF(EX/OP/BS/CONS=LOWMASS/AZM=270/ORG=0,5,0/SIZE=5,8)
  SRF(EX/OP/BS/CONS=LOWMASS/AZM=180/TILT=0/ORG=0,0,8/SIZE=30,5)
  SRF(EX/OP/BS/CONS=LOWMASS/AZM=180/TILT=180/ORG=0,5,0/SIZE=30,5)
  ]
$   The expected temperatures for the medium mass wall are:
$   time  TNmin    TNmax       T+min   T+max      T-max   T-min     TN(SERI)
$    0    0.000    0.000       40.0    40.0       90.0    90.0       0.000
$    4    0.0223   0.0322      41.116  41.610     88.884  88.390     0.040
$    8    0.0613   0.0708      43.066  43.541     86.934  86.459     0.078
$   12    0.0988   0.1079      44.938  45.395     85.062  84.605     0.114
$   16    0.1347   0.1435      46.737  47.175     83.263  82.825     0.149
$   20    0.1693   0.1777      48.464  48.884     81.536  81.116     0.183
$   24    0.2024   0.2105      50.121  50.525     79.879  79.475     0.215
$   28    0.2342   0.2420      51.712  52.100     78.288  77.900     0.246
$   32    0.2648   0.2723      53.240  53.613     76.760  76.387     0.276
$   36    0.2942   0.3013      54.708  55.066     75.292  74.934     0.305
$   40    0.3223   0.3292      56.116  56.460     73.884  73.540     0.332
ZONE [
  GEOM(NAME=ZONE4/RPT=TZ,I/VOL=.01)
  SRF(EX/OP/BS/CONS=MEDMASS/AZM=0/ORG=30,5,0/SIZE=30,8)
  SRF(EX/OP/BS/CONS=MEDMASS/AZM=90/ORG=30,0,0/SIZE=5,8)
  SRF(EX/OP/BS/CONS=MEDMASS/AZM=180/ORG=0,0,0/SIZE=30,8)
  SRF(EX/OP/BS/CONS=MEDMASS/AZM=270/ORG=0,5,0/SIZE=5,8)
  SRF(EX/OP/BS/CONS=MEDMASS/AZM=180/TILT=0/ORG=0,0,8/SIZE=30,5)
  SRF(EX/OP/BS/CONS=MEDMASS/AZM=180/TILT=180/ORG=0,5,0/SIZE=30,5)
  ]
$   The expected temperatures for the high mass wall are:
$   time  TNmin    TNmax       T+min   T+max      T-max   T-min     TN(SERI)
$    0    0.000    0.000       40.0    40.0       90.0    90.0       0.000
$   10    0.0386   0.0443      41.930  42.216     88.070  87.784     0.058
$   20    0.0942   0.0996      44.710  44.979     85.290  85.021     0.111
$   30    0.1466   0.1517      47.330  47.584     82.670  82.416     0.162
$   40    0.1960   0.2008      49.799  50.038     80.201  79.962     0.209
$   50    0.2425   0.2470      52.125  52.350     77.875  77.650     0.255
$   60    0.2863   0.2906      54.316  54.528     75.684  75.472     0.297
$   70    0.3276   0.3316      56.380  56.580     73.620  73.420     0.332
$   80    0.3665   0.3703      58.326  58.514     71.675  71.486     0.375
ZONE [
  GEOM(NAME=ZONE5/RPT=TZ,I/VOL=.01)
  SRF(EX/OP/BS/CONS=HIMASS/AZM=0/ORG=30,5,0/SIZE=30,8)
  SRF(EX/OP/BS/CONS=HIMASS/AZM=90/ORG=30,0,0/SIZE=5,8)
  SRF(EX/OP/BS/CONS=HIMASS/AZM=180/ORG=0,0,0/SIZE=30,8)
  SRF(EX/OP/BS/CONS=HIMASS/AZM=270/ORG=0,5,0/SIZE=5,8)
  SRF(EX/OP/BS/CONS=HIMASS/AZM=180/TILT=0/ORG=0,0,8/SIZE=30,5/
      RPT=HC,I,HO,I,TI,I)   $ Report to insure HC=1, HO=4, TZ=TI.
  SRF(EX/OP/BS/CONS=HIMASS/AZM=180/TILT=180/ORG=0,5,0/SIZE=30,5)
  ]
```

```
$   ZONE6 tests that all three SERI walls reach the same steady state
$   conductance becaues all have the same U-value (.0704).  This gives an
$   expected heating or cooling load of (.0704*860.*25.=) 1514. Btu/h.
ZONE [
  GEOM(NAME=ZONE6/RPT=HLS,I,CLS,I/VOL=.01)
  SRF(EX/OP/BS/CONS=LOWMASS/AZM=0/ORG=30,5,0/SIZE=30,8)
  SRF(EX/OP/BS/CONS=LOWMASS/AZM=90/ORG=30,0,0/SIZE=5,8)
  SRF(EX/OP/BS/CONS=MEDMASS/AZM=180/ORG=0,0,0/SIZE=30,8)
  SRF(EX/OP/BS/CONS=MEDMASS/AZM=270/ORG=0,5,0/SIZE=5,8)
  SRF(EX/OP/BS/CONS=HIMASS/AZM=180/TILT=0/ORG=0,0,8/SIZE=30,5)
  SRF(EX/OP/BS/CONS=HIMASS/AZM=180/TILT=180/ORG=0,5,0/SIZE=30,5)
  ]
SYSTEM [
  SYS(NAME=LOADS)
  DES(ZONE=ZONE1/HTWS=HEAT90/HTFROM=1MAR/HTTHRU=30APR/
                 CLWS=COOL40/CLFROM=1MAY/CLTHRU=28FEB)
  DES(ZONE=ZONE2/HTWS=HEAT90/HTFROM=1MAR/HTTHRU=30APR/
                 CLWS=COOL40/CLFROM=1MAY/CLTHRU=28FEB)
  UNC(ZONE=ZONE3)
  UNC(ZONE=ZONE4)
  UNC(ZONE=ZONE5)
  DES(ZONE=ZONE6/HTWS=SET65/HTFROM=1JAN/HTTHRU=31DEC/
                 CLWS=SET65/CLFROM=1JAN/CLTHRU=31DEC)
]
```

```
$   BDP-3   BDP input file for testing radiant interchange calculations using
$   using the mean radiant temperature (MRT) network method.
$   This uses environment EFP-1.  Actually the weather data is not used in
$   the simulation, but an ENVTFL is required.
$
PROJECT [
  RC(DEM/UIN=ENGLISH/UOUT=ENGLISH/
     DESC='RADIANT INTERCHANGE TESTS')
  RPT(HOURLY/FINAL)
  ]
$   The library includes a set of schedules which are on during different
$   hours and are all on during the last three hours of the day.
$   The walls are described by R-valued materials so there is no mass effect
$   and no calculation of conduction transfer functions.  The zones will be
$   maintained at constant temperatures while heating or cooling.
LIBRARY [
  DS(NAME=C1/FFC=3*0,3*1,15*0,3*1)
  WS(NAME=C1/ALL=C1)
  DS(NAME=C2/FFC=6*0,3*1,12*0,3*1)
  WS(NAME=C2/ALL=C2)
  DS(NAME=C3/FFC=9*0,3*1,9*0,3*1)
  WS(NAME=C3/ALL=C3)
  DS(NAME=C4/FFC=12*0,3*1,6*0,3*1)
  WS(NAME=C4/ALL=C4)
  DS(NAME=C5/FFC=15*0,3*1,3*0,3*1)
  WS(NAME=C5/ALL=C5)
  DS(NAME=C6/FFC=18*0,3*1,3*1)
  WS(NAME=C6/ALL=C6)
  MATL(NAME=R4/R=4.0)
  CONS(NAME=WALL4/MATL=0,R4)
  DS(NAME=HC/DESC='ZONE HEATING TEMPERATURES'/T=24*68.)
  DS(NAME=CC/DESC='ZONE COOLING TEMPERATURES'/T=24*78.)
  WS(NAME=HEAT/DESC='HEATING'/ALL=HC)
  WS(NAME=COOL/DESC='COOLING'/ALL=CC)
  ]
$   This simulation uses the detailed radiant interchange algorithm (RIM=2).
$   The simpler MRT network algorithm can also be tested by setting RIM=1.
$   The default inside convection coefficient is used (HI=0).
$   It uses a very tight loads convergence criterion.
BUILDING [
  SIM(SLDS=0/HTB=0/RIM=2/HI=0/CNVG=.001,.000001,.01,12/
      ZON=ZONE1,ZONE2,ZONE3,ZONE4,ZONE5,ZONE6/ SYS=LOADS)
  ]
$   ZONE1 tests steady state conduction in a simple two wall zone.
$   Since the walls and outside temperatures are identical, the inside
$   surface temperatures are identical and there should be no radiant
$   interchange between the walls.  The inside convection coefficient
$   for vertical walls with HI=0 should be 0.5424 Btu/h ft2 F.
$   The total U-value of the wall is 0.1711 .  The expected heating load
$   for ZONE1 is (0.1711*2000.*20.=) 6845. Btu/h.
ZONE [
  GEOM(NAME=ZONE1/VOL=0.01/RPT=HLS,T)
  SRF(EX/OP/BS/CONS=WALL4/AZM=0/SIZE=100,10)
    OSC(CT=48/CTP=1)
```

```
  SRF(EX/OP/BS/CONS=WALL4/AZM=180/SIZE=100,10)
    OSC(CT=48/CTP=1)
  ]
$   ZONE2 consists of a single wall identical to the walls in ZONE1 and
$   a partition (IN/OP/BS) surface of equal area.  This creates a more
$   complex thermal network:
$
$           exterior wall                         partition
$           |////////////|                      |////////////|
$           |////////////| --------Q21--------  |////////////|
$           |////////////|/                    \|////////////|
$           *----Q01----*                       *----Q22----*
$           |////////////|\                    /|////////////|
$           |////////////| ---QZ1---*---QZ2---  |////////////|
$           |////////////|                      |////////////|
$          TO           T1         TZ          T2           T2
$
$   Both sides of the partition are at the same temperature so, since the
$   thermal resistance is only an R-value, there is no conductive heat
$   flux, Q22, in the partition.  This leaves four heat flux paths:
$   (1)  Q01 = U (TO - T1)  conduction in the exterior wall,
$   (2)  QZ1 = H (TZ - T1)  convection to the exterior wall,
$   (3)  QZ2 = H (TZ - T2)  convection to the partition, and
$   (4)  Q21 = SF (T2**4 - T1**4)  radiation between the walls.
$   S = 0.17141E-8 Btu/h ft2 R4 (Stefan-Boltzmann constant);
$   F = 1/(1/E1+1/E2-1) = 0.818182 for E1=E2=0.90 (radiation interchange
$        factor between two surfaces which can see only each other);
$   Temperatures must be in degrees Rankine (= Fahrenheit + 459.67);
$   H = 0.5424 Btu/h ft2 F;
$   U = 0.25 Btu/h ft2 F.
$   The heat balances at surfaces 1 and 2 are:
$   (1)  Q01 + QZ1 + Q21 = 0   ,
$   (2)  QZ2 = Q21  .
$   Solving simultaneously with TO = 48F and TZ = 68F gives T1 = 63.523F,
$   T2 = 65.322F, and Q01 = -3.881 Btu/h ft2.  For the entire wall the
$   expected heating load is 7762. Btu/h.
ZONE [
  GEOM(NAME=ZONE2/VOL=0.01/RPT=HLS,T)
  SRF(EX/OP/BS/CONS=WALL4/AZM=0/SIZE=10,200/RPT=TI,I)
    OSC(CT=48./CTP=1)
  SRF(IN/OP/BS/CONS=WALL4/AZM=180/SIZE=10,200/RPT=TI,I)
  ]
$   ZONE3 is identical to ZONE2 except that it is in a cooling mode.
$   TO = 98F and TZ = 78F gives T1 = 82.428F, T2 = 80.752F, and
$   Q01 = 3.893 Btu/h ft2.  The expected cooling load is 7786. Btu/h.
$   Note that this load is not exactly equal to the heating load for ZONE2
$   even though there is a 20 degree temperature difference for both
$   zones.  This is because of the nonlinear nature of radiant transfer.
ZONE [
  GEOM(NAME=ZONE3/VOL=0.01/RPT=CLS,T)
  SRF(EX/OP/BS/CONS=WALL4/AZM=0/SIZE=10,200/RPT=TI,I)
    OSC(CT=98./CTP=1)
  SRF(IN/OP/BS/CONS=WALL4/AZM=180/SIZE=10,200/RPT=TI,I)
  ]
```

```
$   ZONE4 test the distribution of radiant gains from scheduled loads.
$   This is similar to the test in BDP-1.  Another test is required
$   because the MRT network method uses a different algorithm for the
$   radiant gains.  31.55% (=(1/.5424)/(4+1/.5424)) of the radiant energy
$   is lost to the outside.  The conductive heat loss is 684.5 Btu/h.
$   The expected hourly heating loads for ZONE4 are:
$   hours 1-6       684.5    684.5    684.5    584.5    584.5    584.5
$   hours 7-12      600.3    600.3    600.3    616.0    616.0    616.0
$   hours 13-18     584.5    584.5    584.5    600.3    600.3    600.3
$   hours 19-24     616.0    616.0    616.0    179.1    179.1    179.1
ZONE [
  GEOM(NAME=ZONE4/VOL=0.01/RPT=HLS,T)
  SRF(EX/OP/BS/CONS=WALL4/AZM=0/SIZE=10,10)
    OSC(CT=48/CTP=1)
  SRF(EX/OP/BS/CONS=WALL4/AZM=180/SIZE=10,10)
    OSC(CT=48/CTP=1)
  EQP(WS=C1/CAP=0.1/LAT=0/RAD=0/LOST=0/GS)
  EQP(WS=C2/CAP=0.1/LAT=0/RAD=.5/LOST=0/GS)
  EQP(WS=C3/CAP=0.1/LAT=0/RAD=1.0/LOST=0/GS)
  LIT(WS=C4/CAP=0.1/RA=0/RAD=0/VIS=0/REP=0)
  LIT(WS=C5/CAP=0.1/RA=0/RAD=.3/VIS=.2/REP=0)
  LIT(WS=C6/CAP=0.1/RA=0/RAD=.7/VIS=.3/REP=0)
  ]
$   Zones 5 and 6 test the interzone partition algorithm.  Since both
$   zones are identical, the interzone surface should be equivalent to a
$   partition.  The heating loads for Zones 5 and 6 should be identical
$   to ZONE4's heating load.
ZONE [
  GEOM(NAME=ZONE5/VOL=0.01/RPT=HLS,T)
  SRF(EX/OP/BS/CONS=WALL4/AZM=0/SIZE=10,200)
    OSC(CT=48./CTP=1)
  SRF(IN/OP/BS/CONS=WALL4/AZM=180/SIZE=10,200/ZONE=ZONE6)
  ]
ZONE [
  GEOM(NAME=ZONE6/VOL=0.01/RPT=HLS,T)
  SRF(EX/OP/BS/CONS=WALL4/AZM=0/SIZE=10,200)
    OSC(CT=48./CTP=1)
  SRF(IN/OP/BS/CONS=WALL4/AZM=180/SIZE=10,200/ZONE=ZONE5)
  ]
SYSTEM [
  SYS(NAME=LOADS)
  DES(ZONE=ZONE1/HTWS=HEAT/CLWS=COOL)
  DES(ZONE=ZONE2/HTWS=HEAT/CLWS=COOL)
  DES(ZONE=ZONE3/HTWS=HEAT/CLWS=COOL)
  DES(ZONE=ZONE4/HTWS=HEAT/CLWS=COOL)
  DES(ZONE=ZONE5/HTWS=HEAT/CLWS=COOL)
  DES(ZONE=ZONE6/HTWS=HEAT/CLWS=COOL)
  ]
```

```
$   BDP-4   BDP input file to test latent load and contaminant calculations.
$   Contaminant concentration is computed by an algorithm which is nearly
$   identical to the mositure concentration and latent load algorithm.
$   This uses environment EFP-4.
$
PROJECT[
  RC(DEM/UIN=ENGLISH/UOUT=ENGLISH/
    DESC='LATENT LOADS AND CONTAMINANT TESTS')
  RPT(HOURLY/FINAL)
  ]
$   The temperature and humidity control schedules cause the minimum humidity
$   ratio (at TZ=68F and RH=40%) to be .005903 (lb H20/lb air).  The maximum
$   humidity ratio (at TZ=78F and RH=60%) is .012523 .
LIBRARY[
$ LIB(ALL)
  DS(NAME=C/FFC=24*1)
  WS(NAME=C/ALL=C)
  DS(NAME=STEP/FFC=6*0.0,12*1.0,6*0.0)
  WS(NAME=STEP/ALL=STEP)
  DS(NAME=K1/FFC=6*1,18*0)
  WS(NAME=WK1/ALL=K1)
  DS(NAME=K2/FFC=6*0,6*1,12*0)
  WS(NAME=WK2/ALL=K2)
  DS(NAME=K3/FFC=12*0,6*1,6*0)
  WS(NAME=WK3/ALL=K3)
  DS(NAME=K4/FFC=18*0,6*1)
  WS(NAME=WK4/ALL=K4)
  MATL(NAME=R10/R=10.0)
  CONS(NAME=WALL10/MATL=0,R10)
  DS(NAME=HEATD/DESC='DAY HEATING'/T=24*68.0)
  DS(NAME=COOLD/DESC='DAY COOLING'/T=24*78.0)
  WS(NAME=HEATW/DESC='WEEK HEATING'/ALL=HEATD)
  WS(NAME=COOLW/DESC='WEEK COOLING'/ALL=COOLD)
  DS(NAME=HUMD/DESC='DAY HUMIDIFYING'/FFC=24*0.4)
  WS(NAME=HUMW/DESC='WEEK HUMIDIFYING'/ALL=HUMD)
  DS(NAME=DEHUMD/DESC='DAY DEHUMIDIFYING'/FFC=24*0.6)
  WS(NAME=DEHUMW/DESC='WEEK DEHUMIDIFYING'/ALL=DEHUMD)
  ]
$   The LAT command causes the calculation of latent loads.
$   Try CTS with different timesteps to test the trade-off of accuracy vs.
$   calculation time.  Relatively long steps should be possible when
$   conditions change slowly.  Two contaminants are defined.
BUILDING[
  SIM(LAT/SLDS=0/HTB=0/HO=0/HI=0/CTS=60./
     ZON=ZONE1,ZONE2,ZONE3/SYS=LOADS/RPT=TA,A)
  CTM(NAME=CO/ACC=0/WS=C)
  CTM(NAME=CO2/ACC=0/WS=C)
  ]
$   ZONE1 tests the operation of scheduled latent gains.  The reported
$   latent loads (RPT=CLL,T) should equal the scheduled latent gains.
$   The conductive gains through the walls are (.0844*200*20=) 337.7 Btu/h.
$   The convective portion of the scheduled equipment loads will be added
$   to the above value and reported as the sensible cooling load (CLS,T).
$   The sum of the sensible and latent loads should be 437.7 Btu/h at all hours.
```

```
ZONE[
  GEOM(NAME=ZONE1/VOL=1200./RPT=CLS,T,CLL,T)
  EQP(WS=WK1/CAP=0.1/LAT=0.0/RAD=0.0/LOST=0.0/ST)
  EQP(WS=WK2/CAP=0.1/LAT=0.5/RAD=0.0/LOST=0.0/ST)
  EQP(WS=WK3/CAP=0.1/LAT=0.75/RAD=0.0/LOST=0.0/ST)
  EQP(WS=WK4/CAP=0.1/LAT=1.0/RAD=0.0/LOST=0.0/ST)
  SRF(EX/OP/BS/CONS=WALL10/AZM=0/TILT=90/ORG=10,10,0/SIZE=10,10)
  OSC(CT=98./CTP=1)
  SRF(EX/OP/BS/CONS=WALL10/AZM=180/TILT=90/ORG=0,0,0/SIZE=10,10)
  OSC(CT=98./CTP=1)
  ]
$   ZONE2 tests the calculation of latent loads due to infiltration.
$   The infiltration is constant at 20 cfm, or one air change, per hour.
$   When the ambient air temperature is 48F, the sensible heating load
$   due to conduction is 337.7 Btu/h, and the sensible heating load due
$   to infiltration is about 432. Btu/h.  ASHRAE gives two slightly
$   different formulae for this.  The result above is according to
$   equation 8, page 25.10 of the 1981 Fundamentals Handbook which gives
$   QS = 1.08*(cfm)*(temperature difference - F).  Equation 25, page 26.30
$   gives QS = 1.10*(cfm)*(temperature difference).
$   The total sensible heating and cooling loads should be about 769.7 Btu/h.
$   Equation 29, page 26.30 gives the latent load as
$   QL = 4840*(cfm)*(humidity ration difference).  During the 6 hours of
$   low ambient humidity, TARP should compute a humidification load of
$   (4840*20*(0.005903-0.003004)=) 280.6 Btu/h.  During the 6 hours of
$   high ambient humidity, the dehumidification load should be
$   (4840*20*(0.015832-0.012523)=) 320.3 Btu/h.
$   Note that the mass of the zone air introduces a transient effect into
$   zone air temperature, and sensible and latent loads.
ZONE[
  GEOM(NAME=ZONE2/VOL=1200./RPT=TZ,A,OAF,T,HLS,T,HLL,T,CLS,T,CLL,T)
  INF(WS=C/CAP=20./C=1/T=0/V=0/VV=0)
  SRF(EX/OP/BS/CONS=WALL10/AZM=0/TILT=90/ORG=10,10,0/SIZE=10,10)
  OSC(TAP=1)
  SRF(EX/OP/BS/CONS=WALL10/AZM=180/TILT=90/ORG=0,0,0/SIZE=10,10)
  OSC(TAP=1)
  ]
$   ZONE3 tests the calculation of contaminant concentrations.  The first
$   contaminant should reach a steady concentration where the generation
$   rate matches the removal rate due to infiltration.  The density of air
$   at 68F is about 0.75 lb/ft3 and the infiltration rate is 900 ft3/h.
$   This gives 67.5 pounds of air removed per hour.  Since the contaminant
$   generation rate is 1.0 lb/h, the steady state concentration should be
$   (1.0/67.5=) 0.0148 (lb c/lb air).
```

```
$   The second contaminant is generated during only half of the day for an
$   analysis of the transient calculations.  The concentration should follow
$   a simple exponential rise or decay.  Since there is one air change
$   per hour, the time constant is 1/e or 0.3679 .  The following
$   concentrations are expected:
$     time              rise              decay
$       0               0.0               0.01481
$       1               0.00936           0.00545
$       2               0.0128            0.00200
$       3               0.0141            0.00074
$       4               0.0145            0.00027
$       5               0.0147            0.00010
ZONE [
  GEOM(NAME=ZONE3/VOL=900/RPT=HLS,T,CC1,A,CC2,A)
  INF(WS=C/CAP=15./C=1/T=0/V=0/VV=0)
  CTM(NAME=CO/CGR=1/WS=C)
  CTM(NAME=CO2/CGR=1/WS=STEP)
  SRF(EX/OP/BS/CONS=WALL10/AZM=0/TILT=90/ORG=10,10,0/SIZE=10,10)
  OSC(CT=48/CTP=1)
  SRF(EX/OP/BS/CONS=WALL10/AZM=180/TILT=90/ORG=0,0,0/SIZE=10,10)
  OSC(CT=48/CTP=1)
  ]
SYSTEM[
  SYS(NAME=LOADS)
  DES(ZONE=ZONE1/HTWS=HEATW/CLWS=COOLW/HUWS=HUMW/DHWS=DEHUMW)
  DES(ZONE=ZONE2/HTWS=HEATW/CLWS=COOLW/HUWS=HUMW/DHWS=DEHUMW)
  DES(ZONE=ZONE3/HTWS=HEATW/CLWS=COOLW)
  ]
```

```
$   BDP-5   BDP input file for testing solar gains calculations.
$   This uses environment EFP-5.
$
$   Report flag 13 is set to print the results of the shadowing calculations.
$   TARP  reports the solar azimuth and altitude for every hour,
$   and it prints the angle of incidence of the sun's rays on every surface
$   which is receiving direct solar radiation.
$   Page 57.4 of the 1982 Applications Handbook gives values of solar altitude
$   (ALT) and azimuth (AZM) angles.  These values are given on the hour
$   in solar time.  TARP computes the values at the half hour in local time.
$   TARP reports azimuth in degrees from north, ASHRAE in degrees from south.
$   The ASHRAE values are:
$   solar      21 March          21 June          21 December
$   time     ALT      AZM      ALT      AZM      ALT      AZM
$     5        -        -      4.2    117.3        -        -
$     6        -        -     14.8    108.4        -        -
$     7     11.4     80.2     26.0     99.7        -        -
$     8     22.5     69.6     37.4     90.7      5.5     53.0
$     9     32.8     57.3     48.8     80.2     14.0     41.9
$    10     41.6     41.9     59.8     65.8     20.7     29.4
$    11     47.7     22.6     69.2     41.9     25.0     15.2
$    12     50.0      0.0     73.5      0.0     26.6      0.0
$   Values are symmetric about noon.  These values are also presented
$   on page 27.6 of the 1981 Fundamentals Handbook.  The angles of incidence
$   are also presented on that page.  They can be compared to the TARP output.
$   They will not be presented here because they are implicit in the solar
$   gains values which will be presented.
$
PROJECT [
  RC(DEM/UIN=ENGLISH/UOUT=ENGLISH/
     DESC='SOLAR GAINS TEST')
  RPT(RNOS=13/HOURLY/DAILY/MONTHLY/FINAL)
  ]
$   The wall materials have an inside solar absorptance of 1.0 to reduce
$   the amount of solar gain which could be reflected back out the window.
$   They also have an extremely high thermal resistance to prevent solar
$   gains being conducted to the outside.  Outer solar absorptances are
$   0.0 to prevent outside solar gains being conducted into the zone.
$   Some walls have OA=1 to determine the total radiation incident on
$   various surfaces.  The transmittance and shading coefficient models
$   of windows are both tested.  A library report prints the window
$   optical properties.
```

```
LIBRARY  [
  LIB(CONS)
  DS(NAME=C/FFC=24*1.0)
  WS(NAME=C/ALL=C)
  MATL(NAME=R10000/R=10000.)
  MATL(NAME=SPDS/R=.01/GLASS/TRNS=.86)
  MATL(NAME=SHDC/R=.01/GLASS/SC=1.0)
  CONS(NAME=WALL1/MATL=0,R10000/IA=1.0/OA=0.0)
  CONS(NAME=WALL2/MATL=0,R10000/IA=1.0/OA=1.0)
  CONS(NAME=WINDOW1/MATL=0,SPDS)
  CONS(NAME=WINDOW2/MATL=0,SHDC)
  DS(NAME=HC/DESC='ZONE HEATING TEMPERATURES'/T=24*68)
  DS(NAME=CC/DESC='ZONE COOLING TEMPERATURES'/T=24*78)
  WS(NAME=HEAT/DESC='HEATING'/ALL=HC)
  WS(NAME=COOL/DESC='COOLING'/ALL=CC)
  ]
$   The simulation controls are set for:  high loads convergence,
$   no shadowing (no base surface origins needed), the simple MRT
$   network algorithm, and inside and outside convection coefficients
$   corresponding to the AHSRAE values used  to compute solar gains.
$   A modification of this test could use the default convetion coefficients.
$   It should give similar answers.
$   Another modification would be to mirror all zones so surfaces face north
$   instead of south, etc., and use EFP-4 modified for the southern
$   hemisphere.
BUILDING [
  SIM(CNVG=.01,.00001,.10,12/SLDS=0/HTB=0/RIM=1/HO=1,4.0/HI=1,1.46/
      RPT=TA,A,IT,T,IB,T,IS,T/
      ZON=BOXN,BOXE,BOXS,BOXW,BOXSC/
      SYS=LOADS)
  ]
$   There are five zones.  The first zone includes a set of six small, high
$   absorptance surfaces which face south and have different tilt angles.
$   The user defined reports will tell the amount of solar energy absorbed
$   (= the amount incident) on each surface.  Ground reflectances are set to
$   zero for comparison to the ASHRAE values from page 57.4 of the 1982
$   Applications Handbook.  Again, ASHRAE and TARP use different reporting
$   times and integration algorithms.  The daily total values should be
$   quite similar.
$   21 March
$   solar                          tilt angles
$   time        0        30        40        50        60        90
$     7        46        55        55        54        51        35
$     8       114       140       141       138       131        89
$     9       173       215       217       213       202       138
$    10       218       273       276       271       258       176
$    11       247       310       313       307       293       200
$    12       257       322       326       320       305       208
$   total    1852      2308      2330      2284      2174      1484
```

```
$   21 June
$   solar                           tilt angles
$   time        0        30        40        50        60        90
$     5         4         3         3         2         2         1
$     6        60        30        18        17        16        10
$     7       123        92        77        59        41        14
$     8       182       159       142       121        97        16
$     9       233       219       202       179       151        47
$    10       272       266       248       224       194        74
$    11       296       296       278       253       221        92
$    12       304       306       289       263       230        98
$   total    2648      2434      2224      1974      1670       610
$   21 December
$   solar                           tilt angles
$   time        0        30        40        50        60        90
$     8        14        39        45        50        54        56
$     9        65       135       152       164       171       163
$    10       107       200       221       235       242       221
$    11       134       239       262       276       283       252
$    12       143       253       275       290       296       263
$   total     782      1480      1634      1740      1796      1646
$
$   The last three surfaces in the zone are used to compute the solar gain
$   due to one square foot of window.  The window is very small in relation
$   to the other two surfaces to reduce the reflection of light out of the
$   zone.  One of the surfaces is a floor which absorbs all beam solar enrgy
$   transmitted into the zone according to the default solar distribution
$   algorithm.  The solar gain appear as a cooling load reported by "CLS,T".
$   A ground reflectance of 0.2 (the TARP default) is used.
$   The solar gain factors for standard glazing at 40 degrees latitude
$   are presented on page 27.32 of the 1981 Fundamentals Handbook.
$   The ASHRAE reported values for four window azimuths are:
$   21 March
$   solar             window directions
$   time      north      east     south      west
$     7         9       163        22         8
$     8        16       218        74        16
$     9        21       203       128        21
$    10        25       153       171        25
$    11        28        78       197        28
$    12        29        31       206        31
$    13        28        28       197        78
$    14        25        25       171       153
$    15        21        21       128       203
$    16        16        16       157       218
$    17         9         8        22       163
$   total     228       946      1388       946
```

```
$   21 June
$   solar             window directions
$   time     north      east     south      west
$     5        10        20         1         1
$     6        48       151        13        13
$     7        37       207        22        21
$     8        30       216        29        27
$     9        33       192        45        32
$    10        35       145        69        35
$    11        38        81        88        38
$    12        38        41        95        41
$    13        38        38        88        81
$    14        35        35        69       145
$    15        33        32        45       192
$    16        30        27        29       216
$    17        37        21        22       207
$    18        48        13        13       151
$    19        10         1         1        20
$   total     430      1200       716      1200
$   21 December
$   solar             window directions
$   time     north      east     south      west
$     8         3        67        50         3
$     9        10       135       151        10
$    10        14       113       210        14
$    11        17        56       242        17
$    12        18        19       253        19
$    13        17        17       242        56
$    14        14        14       210       113
$    15        10        10       151       135
$    16         3         3        50        67
$   total     104       427      1550       427
$   The zone named BOXN has a window facing north; BOXE faces east;
$   BOXS faces south; BOXW faces west.  Zone BOXSC has a different window
$   type and faces south.
$   It should be noted that the ASHRAE solar gain values were computed
$   with an anisotropic diffuse radiation model, while the irradiation values
$   were computed with an isotropic model.  TARP uses an isotropic model for
$   both calculations.
ZONE [
  GEOM(NAME=BOXN/VOL=0.01/RPT=CLS,T)
  SRF(EX/OP/BS/CONS=WALL2/AZM=180/TILT=00/SIZE=1,1/GRC=0/RPT=QSO,T)
  SRF(EX/OP/BS/CONS=WALL2/AZM=180/TILT=30/SIZE=1,1/GRC=0/RPT=QSO,T)
  SRF(EX/OP/BS/CONS=WALL2/AZM=180/TILT=40/SIZE=1,1/GRC=0/RPT=QSO,T)
  SRF(EX/OP/BS/CONS=WALL2/AZM=180/TILT=50/SIZE=1,1/GRC=0/RPT=QSO,T)
  SRF(EX/OP/BS/CONS=WALL2/AZM=180/TILT=60/SIZE=1,1/GRC=0/RPT=QSO,T)
  SRF(EX/OP/BS/CONS=WALL2/AZM=180/TILT=90/SIZE=1,1/GRC=0/RPT=QSO,T)
  SRF(EX/OP/BS/CONS=WALL1/AZM=0/SIZE=10,10)
    SRF(EX/TR/SS/CONS=WINDOW1/SIZE=1,1)
  SRF(EX/OP/BS/CONS=WALL1/AZM=180/TILT=180/SIZE=10,10)
  ]
```

```
ZONE [
  GEOM(NAME=BOXE/VOL=0.01/RPT=CLS,T)
  SRF(EX/OP/BS/CONS=WALL1/AZM=90/SIZE=10,10)
    SRF(EX/TR/SS/CONS=WINDOW1/SIZE=1,1)
  SRF(EX/OP/BS/CONS=WALL1/AZM=180/TILT=180/SIZE=10,10)
  ]
ZONE [
  GEOM(NAME=BOXS/VOL=0.01/RPT=CLS,T)
  SRF(EX/OP/BS/CONS=WALL1/AZM=180/SIZE=10,10)
    SRF(EX/TR/SS/CONS=WINDOW1/SIZE=1,1)
  SRF(EX/OP/BS/CONS=WALL1/AZM=180/TILT=180/SIZE=10,10)
  ]
ZONE [
  GEOM(NAME=BOXW/VOL=0.01/RPT=CLS,T)
  SRF(EX/OP/BS/CONS=WALL1/AZM=270/SIZE=10,10)
    SRF(EX/TR/SS/CONS=WINDOW1/SIZE=1,1)
  SRF(EX/OP/BS/CONS=WALL1/AZM=180/TILT=180/SIZE=10,10)
  ]
ZONE [
  GEOM(NAME=BOXSC/VOL=0.01/RPT=CLS,T)
  SRF(EX/OP/BS/CONS=WALL1/AZM=180/SIZE=10,10)
    SRF(EX/TR/SS/CONS=WINDOW2/SIZE=1,1)
  SRF(EX/OP/BS/CONS=WALL1/AZM=180/TILT=180/SIZE=10,10)
  ]
SYSTEM [
  SYS(NAME=LOADS)
  DES(ZONE=BOXN/HTWS=HEAT/CLWS=COOL)
  DES(ZONE=BOXE/HTWS=HEAT/CLWS=COOL)
  DES(ZONE=BOXS/HTWS=HEAT/CLWS=COOL)
  DES(ZONE=BOXW/HTWS=HEAT/CLWS=COOL)
  DES(ZONE=BOXSC/HTWS=HEAT/CLWS=COOL)
]
```

```
$   EFP-1   EFP input file for testing steady state and scheduled loads.
$   The ground temperature is 25 degreees lower than the zone temperatures.
$   The multiple air temperatures are primarily to test the operation of
$   the baseboard heat algorithm (4.5).
$   Solar radiation will not be used in the simulation.
$
RC(DEM/LIST/UIN=ENGLISH/UOUT=ENGLISH)
LOC(DESC='ON TIME ZONE MERIDIAN'/LATD=40./LONG=90./TZ=6)
GRND(GRT=12*43)
DAY(DESC='24 TEMPERATURES'/DATE=21MAR/CLR=1/CLD=24*0/
  TA=2,4,6,8,10,12,14,16,18,20,22,24,26,28,30,32,34,36,38,40,42,44,46,48)
```

```
$   EFP-2   EFP input for the transient conduction tests.
$
$   This weather pattern consists of four months of constant temperatures
$   except for two step changes:  from 40 to 90 and back.  The long periods
$   of constant temperature are necessary to allow the massive walls to
$   reach steady state.  The time periods of interest are the first few
$   hours or days after the temparature step changes.
$
RC(DEM/UIN=ENGLISH/UOUT=ENGLISH)
LOC(DESC='ON TIME ZONE MERIDIAN'/LATD=40./LONG=90./TZ=6)
GRND(GRT=12*55)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=1FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=2FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=3FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=4FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=5FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=6FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=7FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=8FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=9FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=10FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=11FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=12FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=13FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
```

```
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=14FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=15FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=16FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=17FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=18FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=19FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=20FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=21FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=22FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=23FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=24FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=25FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=26FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=27FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=28FEB/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*90./CLR=0/CLD=24*0/DATE=1MAR/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*90./CLR=0/CLD=24*0/DATE=2MAR/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*90./CLR=0/CLD=24*0/DATE=3MAR/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*40./CLR=0/CLD=24*0/DATE=4MAR/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*90./CLR=0/CLD=24*0/DATE=5MAR/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*90./CLR=0/CLD=24*0/DATE=6MAR/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
DAY(TA=24*90./CLR=0/CLD=24*0/DATE=7MAR/RH=24*.50/PRES=24*405./
     WS=24*5./DIR=24*270.)
$DAY(TA=24*90./CLR=0/CLD=24*0/DATE=8MAR/RH=24*.50/PRES=24*405./
$     WS=24*5./DIR=24*270.)
$DAY(TA=24*90./CLR=0/CLD=24*0/DATE=9MAR/RH=24*.50/PRES=24*405./
$     WS=24*5./DIR=24*270.)
$
$   This file is not shown completely.  The rest of the days in March
$   and all days in April have TA=24*90.  The days in May have TA=24*40.
$   These days will be needed to study the response to a step decrease.
```

```
$   EFP-4   EFP input file for testing latent load calculations.
$   The dew point temperatures should give the following humidity ratios:
$       TD = 27F     W = 0.003004    (lb H2O/lb air  or  kg H2O/kg air)
$       TD = 53F     W = 0.008573
$       TD = 70F     W = 0.015832
$   The dry bulb temperatures are selected to give heating and cooling
$   with temperature differences of 20F and two periods of operation in
$   the zone's deadband between 68F and 78F.
$
  RC(DEM/LIST/ENGLISH)
  LOC(DESC='ON TIME ZONE MERIDIAN'/LATD=40./LONG=90./TZ=6)
  GRND(GRT=12*55)
  DAY(DESC='TEST DAY'/DATE=21MAR/CLR=1/CLD=24*0/TA=6*48,6*73,6*98,6*73/
     TD=6*27,6*53,6*70,6*53)
```

```
$   EFP-5   EFP input file for testing solar gains calculations.
$   The location is set for 40 degrees north latitude and the longitude
$   matching the time zone.  Weather is generated for three dates
$   corresponding to dates (and latitude) available in the ASHRAE
$   Handbooks.
$   Page 57.4 of the 1982 Applications Handbook gives values of direct normal
$   (IB) and total horizontal (IT) irradiation.  These values are given on the
$   hour in solar time.  TARP computes the values at the half hour in local time
$   time.  The ASHRAE values are:
$   solar        21 March          21 June           21 December
$   time         IB       IT       IB       IT       IB       IT
$     5          -        -        22       4        -        -
$     6          -        -        155      60       -        -
$     7          171      46       216      123      -        -
$     8          250      114      246      182      89       14
$     9          282      173      263      233      217      65
$    10          297      218      272      272      261      107
$    11          305      247      277      296      280      134
$    12          307      257      279      304      285      143
$    Remainder of day is symmetric about noon.
$   total     2916     1852     3180     2648     1978     782
$   The TARP daily total values should be quite similar.
$   Ambient temperatures are equal to the zone cooling set point to
$   reduce conductive losses through the walls.
$   The latitude can be changed to LATD=-40 to test TARP solar calculations
$   in the southern hemisphere.
$
RC(DEM/LIST/UIN=ENGLISH/UOUT=ENGLISH)
LOC(DESC='ON TIME ZONE MERIDIAN'/LATD=40./LONG=90./TZ=6)
GRND(GRT=12*55)
DDY(DESC='21 MARCH'/HIGH=78/LOW=78/WB=70/DATE=21MAR/CLR=1)
DDY(DESC='21 JUNE'/HIGH=78/LOW=78/WB=70/DATE=21JUN/CLR=1)
DDY(DESC='21 DECEMBER'/HIGH=78/LOW=78/WB=70/DATE=21DEC/CLR=1)
```

FORM NBS-114A (REV 11-84)

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4. TITLE AND SUBTITLE

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5. AUTHOR(S)

George N. Walton and Kevin Cavanaugh

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

NATIONAL BUREAU OF STANDARDS
U.S. DEPARTMENT OF COMMERCE
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7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

10. SUPPLEMENTARY NOTES

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

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

In this study analytical and empirical tests were performed using the Thermal Analysis Research Program (TARP). TARP was found to be very accurate relative to the analytical tests (calculations for simplified conditions) which covered steady and transient conduction, internal radiant interchange, latent loads, and clear sky solar gains. Six one-room buildings with different wall constructions provided data for the empirical tests. TARP's predicted heating loads were generally within 10 per cent of the predicted heating loads. The prediction of cooling loads was less successful with an average difference from the measured loads of 25 per cent. This error was considered primarily due to uncertainties in the measured cooling loads and the modeling of diffuse solar gains. The analytic tests are now part of the information available on the TARP source code tape.

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

Building energy analysis; computer simulation, thermal analysis research program; validation

13. AVAILABILITY

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