DOE/CS/20057-T2

# Parallel Calculations Between the TC 4.7 Simplified Energy Calculation Procedure and Seven Comprehensive Hourly Simulation Energy Calculation Procedures

DOE/CS/20057--T2

DE81 008318

MASTER

Tamami Kusuda

Chairman
- Chairman Simplified Energy Analysis
ASHRAE Technical Committee on
Energy Calculation (TC 4.7)

October 31, 1980

This report has been prepared for the American Society for Heating, Refrigerating and Air Conditioning Under Contract DE-AC01-78CS20057

ASHRAE RP-205

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It has been reproduced from the best available copy to permit the broadest possible availability.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

## DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

**DISCLAIMER**

**Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.**

The research effort to develop an ASHRAE acceptable simplified energy calculation procedure suitable for small hand and desk calculators was unsuccessful. However, the product of this important work was the report of comparative calculations and analysis by developers and/or agents of seven comprehensive hourly simulation programs using the same building data and location. Results of these studies have been transmitted to DOE and released to the public through normal ASHRAE channels. Additional work in this area is needed under another research grant.

## 1. INTRODUCTION

The successful implementation of Energy Conservation Standards for Building Design such as ASHRAE 90 and DOE BEPS (Building Energy Performance Standards) depends on the availability of a comprehensive yet simple calculation procedure for estimating annual building energy consumption.

Although there are several sophisticated procedures available which are based upon the dynamic simulation of hourly building performance inclusive of envelope transfer, utility system and equipment, these procedures require a very large computer and excessive computer time and cost for most applications. The computer programs are usually very complex and proprietary, which discourages their widespread use by any except computer-oriented energy analysis specialists.

Although simple to use and relatively well accepted for the residential heating fuel analysis, the existing and widely used degree day method is unable to include in its analysis such essential elements of energy calculations as:

1. Climatic data: coincident hourly values for temperature, humidity, solar radiation, and wind data test for a reference year.

2. Building construction: orientation, size, shape, mass and air moisture and heat transfer characteristics.

3. Operational characteristics: setting of thermostat, humidistat ventilation switch, light switch and equipment operation schedule, and occupancy schedule.

4. Utility system and equipment performance: full and part load.

5. Internal thermal load due to lighting, occupancy, cooking, computers, and others.

The objective of the ASHRAE project RP-205 was to develop a simplified energy calculation procedure which is suitable for nonresidential buildings and includes all of the elements specified above, and compares the results with the comprehensive hourly simulation calculation.

The method adopted by TC 4.7 subcommittee for simplified energy calculations is a "bin" method used by the REAP procedure of the Carrier Corporation. In the bin method the heating and cooling requirements of a building are calculated and expressed as a function of the prevailing ambient dry-bulb temperatures. These calculations are obtained for outdoor temperatures in increments of $5^{o}F$. Hourly frequency of these $5^{o}F$ temperature bins are available in the Air Force Manual (AFM) 88-29.

Instead of the simple heat-loss and heat-gain calculation, a relatively comprehensive load calculation, air-side system simulation, and equipment-load estimation are performed at selected bin temeprature points, and the energy consumption at any other point is derived by linear interpolation or extrapolation. The procedure is valid as long as one accepts symplifying notion that the solar and humidity effects are functions of outdoor temperature alone (which is shown to be approximately valid as illustrated later), and that the sequential time effect in dynamic response of building energy performance, such as thermal storage, effect, is relatively unimportant. The important and significant improvement of the TC 4.7 method over the degree-

day method or the conventional bin method is that the rigorous energy calculations including detailed HVAC system simulations are performed for the occupied-hour conditions as well as for the nonoccupied hour conditions.

Although the attractive feature of the improved bin method is its use of conventional calculation procedures, which are familiar to practicing engineers not accustomed to the advanced computer simulation technique, it should be recognized that this new method still requires a relatively comprehensive set of input data.

Five of the major phases of normal energy analysis calculations involve load estimating, selection, design of the air distribution system, the design of the various energy distribution systems, and energy consumption estimates of major equipment such as boiler, chiller, fan, and pump.

TC 4.7 method is essentially identical with the Carrier REAP method except for the load estimating calculation. The load estimation is done by following the cooling load temperature difference concept methods of the 1977 ASHRAE Handbook of Fundamentals to account for the building thermal mass in converting the heat loss/gain into the heating and cooling loads.

For example, traditionally the transmission load was calculated by the product of area, the overall heat transfer coefficient and the temperature difference between indoors and outdoors. The value this obtained is really a heat gain/loss and not necessarily the cooling/heating load, which will be felt by the air-handling unit. This is because some part of the heat transmitted into the space will be abosrbed by the interior surfaces of the room and only the remaining part will be picked up by the air-handling unit. With this in mind, the 1977 ASHRAE Handbook of Fundamentals recommends the use of Cooling Load Temperature Difference (CLTD), which is the indoor/outdoor temperature difference adjusted depending upon the weight of the room thermal mass for roof and exterior walls, in calculating the cooling load.

TC 4.7 subcommittee on the Simplified Energy Calculation prepared a booklet entitled, "A Simplified Energy Calculation Procedure for Use in Energy Con-

servation Standards Activities," in which the details of the load calculation and HVAC and equipment simulation are described.

2. SCHEME OF THE PARALLEL CALCULATION WITH HOURLY SIMULATION PROGRAMS

The subcommittee then decided to compare the simplified procedure with hourly simulation procedures for an office building in Washington, DC with the following HVAC system:

a. terminal reheat with scheduled cold-coil discharger temperature during cooling;

b. double duct with scheduled hot and cold deck temperatures;

c. double-bundle-type heat reclaim system with thermal storage; and

d. standard VAV system with perimeter fan coil to offset transmission.

The central plant for this system is assumed to consist of an electric centrifugal chiller with cooling tower and gas-fired boiler.

Hourly simulation programs to be used for checking the simplified procedures and the names of those who responded to ASHRAE RFP to carry out the energy analysis are:

Ross Meriwether program (ESAS) by C. K. Yuill

TRACE by C. L. Ringquist

AXCESS by G. Reeves

DOE-2 by M. Lokmankekim

E-Cube-III by D. P. Deyoe

BLAST by D. E. Knebel

BLDSIM by G. Shavit

These participants were the originators or those recommended by the originators of their respective energy analyses programs to be most knowledgeable of the algorithmic details of the specific program.

The purpose of this parallel comparison is to study in detail the extent as well as the reasons for agreement and discrepancies due to these two different types of annual energy analysis (bin method and hourly simulation methods).

These users of the hourly simulation programs were expected to understand the simplified procedure and make two parallel calculations, one based upon his hourly simulation method and the other based upon the bin procedure. In this way, discrepancies in the energy calculations resulting from different interpretations of the same building data and heating and ventilation systems by different energy analysts, which were a major cause of problem in the similar previous efforts, would be minimized. Although this dual calculation approach by each of the participants is more expensive and more time consuming than the approach wherein a simplified calculation was done by a single and separate person, it was considered helpful for obtaining more critical evaluations of the simplified procedure.

The building data, weather data (1957, Washington, DC weather tapes) and equipment performance data were provided by the National Bureau of Standards. The participants were to produce reports which entail:

1. Input and output listings of hourly simulation calculations using their own computer programs.

2. Calculation worksheets on the simplified calculation method.

3. Critique, shortcomings or comment on the simplified calculations.

4. Time required to complete manual calculations and time to become familiar with the simplified energy analysis procedure. Also time to prepare input data.

5. List of assumptions required to perform the simplified analysis beyond those common to all.

6. Opinions for explaining the difference, if the results obtained by the hourly simulation method and the simplified method are different.

TC 4.7 subcommittee for Simplified Energy Calculation was responsible for the monitoring of the program as well as the review and acceptance of the final reports.

Commencing February 28, 1978, each of the subcontractors was authorized to undertake computer and manual calculations and report preparation. Subcontracts for this purpose were executed under the terms of DOE Contract No. DE-AC01-78CS20057 (formerly ET-78-C-01-4221).

## 3. RESULTS OF THE PARALLEL CALCULATIONS

By the time of the ASHRAE annual meeting of 1979 (June) all the parallel calculations were completed and reports submitted. Table A-1 through A-4 summarize the comparative results for four different HVAC systems in terms of annual energy consumption per unit gross square foot of floor area. Unexpectedly good agreements were obtained for the cooling energy conservation for most of the parallel runs except BLDSIM and TRACE. The agreement between the simplified method and the hourly simulation method for the annual heating energy consumption are considerably poorer than the cooling energy consumption, except for E-CUBE-III. Again, the BLDSIM and TRACE tend to deviate from the general trend.

It is understood that these latter two programs employ considerally more sophisticated HVAC system simulation than the rest of the hourly simulation programs. The sophisticated simulation also requires more sophisticated or

more detailed input data than the simplified procedure.

Where the input is inadequate for satisfying the very comprehensive algorithm requirement, the participant had to make arbitrary assumptions based upon his best judgement.. Most of the participants complained that the building and operational schemes specified for the sample problem by the TC 4.7 subcomittee was unrealistically simplistic and did not match the sophistication of the hourly simulation computer requirement.

In order to respond to this criticism, Table B is shown to compare the result of simulation comparative analysis done by the AIA Research Corporation and DOE. Each of the four comparison calculations in Table B were, however, done by separate energy analysts for very realistic and extremely sophisticated buildings with very realistic HVAC systems. Here the agreement among the hourly simulation programs are poorer than those between the hourly program and the simplified TC 4.7 method except in the case for the store. The small heating energy consumption prediction by the TC 4.7 method for the store points out a basic deficiency of the TC 4.7 method in that it ignores the morning warm-up (transient effect) and it mixes perimeter heat gain of the south zone solar with the north side heat gain. The latter deficiency can be avoided if each zone is considered a separate building so that the zone solar heat gain mixing does not take place.

4. MAJOR REASONS OF DISCREPANCIES BETWEEN THE HOURLY SIMULATION TECHNIQUE AND THE SIMPLIFIED TC 4.7 METHOD

The parallel calculation participants stated that the TC 4.7 simplified method could not produce the annual energy consumption estimate compatible with that obtained by the hourly simulation program because of the following reasons.

1. Transient effects on controls (time dependent thermostat andf fan-switch setting) are not included in the TC 4.7 method.

2. Thermal storage effect of building expecially in terms of the evening cool-down and morning pick-up cannot be simulated by

the simplified method. This could also affect the fan power consumption as well.

3. In order to use the TC 4.7 method, building has to be overly simplified, otherwise the computation effect becomes too excessive.

4. Part load efficiency characteristic of equipment cannot be handled by the simplified method.

5. A linear correlation between the solar radiation and outdoor temperature may not be reasonable in some areas.

6. The deed band operator cannot be simulated.

7. Energy storage systems cannot be simulated.

8. Unconditioned spaces cannot be treated properly.

These are accurate statements but cannot be incorporated into the present TC 4.7 method, because it is a steady-state method incapable of handling time-dependent processes.

## 5. OTHER PROBLEMS

Without exception, all the participants complained about the vagueness of the written procedure, which necessitated a large amount of learning time, as shown in Table C. Most of the participants, however, expressed that the procedure is extremely simple to use, once they understood basic flow of the computational process. The amount of repetitious computation, however, even for this simple building was so exhaustive and could discourage the routine use for the production type calculations unless a programmable calculator, or desk top computer were used.

There is no doubt that the stream-lined documentation for the procedure will have to be developed on rigorously defined step-by-step algorithms if

the TC 4.7 procedure is to be adopted as the ASHRAE recommended simplified energy analysis program.

6. SUMMARY

1. TC 4.7 procedure does produce similar results as compared against hourly simulation programs if used by the same energy analyst.

2. TC 4.7 procedure vs. BLAST, DOE-2 and AXCESS on very complex large office building, hospital, warehouse and department store yielded the similar comparisons such as follows

3. Differences between the TC 4.7 procedure results and the hourly simulation results are smaller than those due to the different hourly simulation program.

4. TC 4.7 method can be familiarized by an average engineer within two weeks.

5. With programmable calculators and well developed step-by-step worksheet, the energy analysis of an office building could be completed within three weeks.

Table A-1 Summary of ASHRAE RP-205
Comparative Energy Calculation Between the
Hourly Simulation Method and Simplified TC 4.7 Method
For - Terminal Reheat System

| | Light Equip kW/yr/ft$^2$ | Fan kW/yr/ft$^2$ | Cooling Plant kW/yr/ft$^2$ | Heating Gas cf/yr/ft$^2$ |
|---|---|---|---|---|
| TC 4.7 | 11.1 | 8.80 | 10.07 | 107.28 |
| E-CUBE-III | 11.1 | 6.98 | 9.78 | 114.89 |
| TC 4.7 | 11.84 | 15.07 | 9.84 | 176.5 |
| ESAS | 11.84 | 9.79 | 8.16 | 148.4 |
| TC 4.7 | 12.63 | 8.62 | 4.84 | 123.14 |
| BLDSIM | 12.63 | 7.04 | 5.40 | 74.90 |
| TC 4.7 | 11.69 | 13.69 | 13.25 | 159.1 |
| BLAST | 11.16 | 13.87 | 12.39 | 166.9 |
| TC 4.7 | | | 24.2* | 97.0 |
| DOE-2 | | | 24.5 | 105.0 |
| TC 4.7 | | | 24.7* | 127. |
| AXCESS | | | 22.8 | 137. |
| TC 4.7 | 11.25 | 11.9 | 7.07 | 70.96 |
| TRACE | 11.25 | 8.0 | 4.2 | 82.60 |

*Sum of all the electrical consumption

Table A-2 Summary of ASHRAE RP-205
Comparative Energy Calculation Between the
Hourly Simulation Method and Simplified TC 4.7 Method
For - Dual Duct System

| | Light Equip $kW/yr/ft^2$ | Fan $kW/yr/ft^2$ | Cooling Plant $kW/yr/ft^2$ | Heating Gas $cf/yr/ft^2$ |
|---|---|---|---|---|
| TC 4.7 E-CUBE-III | This system was not analyzed by E-CUBE-III because of errors in the program | | | |
| TC 4.7 | 11.8 | 15.1 | 5.1 | 22.9 |
| ESAS | 11.8 | 9.8 | 5.2 | 22.9 |
| TC 4.7 | 12.6 | 8.7 | 3.3 | 76.77 |
| BLDSIM | 12.6 | 7.2 | 4.4 | 44.25 |
| TC 4.7 | 11.7 | 13.7 | 9.2 | 62.95 |
| BLAST | 11.2 | 13.9 | 7.9 | 53.87 |
| TC 4.7 | | | 23.3* | 78.76 |
| DOE-2 | | | 23.1 | 82.49 |
| TC 4.7 | | | 21.4* | 67.0 |
| AXCESS | | | 21.1 | 90.0 |
| TC 4.7 | 11.25 | 8.0 | 2.62 | 9.29 |
| TRACE | 11.25 | 11.09 | 4.14 | 29.04 |

*Sum of all the electrical consumption

Table A-3 Summary of ASHRAE RP-205
Comparative Energy Calculation Between the
Hourly Simulation Method and Simplified TC 4.7 Method
For - VAV and 4-Pipe Fan Coil

| | Light Equip $kW/yr/ft^2$ | Fan $kW/yr/ft^2$ | Cooling Plant $kW/yr/ft^2$ | Heating Gas $cf/yr/ft^2$ |
|---|---|---|---|---|
| TC 4.7 | 11.1 | 1.10 | 4.50 | 14.77 |
| E-CUBE-III | 11.1 | 1.50 | 4.95 | 15.08 |
| TC 4.7 | 11.8 | 11.5 | 9.0 | 64.7 |
| ESAS | 11.8 | 9.2 | 8.0 | 73.1 |
| TC 4.7 | 12.6 | 1.4 | 3.6 | 28.86 |
| BLDSIM | 12.6 | 2.4 | 2.8 | 16.78 |
| TC 4.7 | 11.7 | 2.4 | 4.7 | 14.77 |
| BLAST | 11.2 | 2.6 | 4.6 | 16.70 |
| TC 4.7 | | | 17.3* | 8.9 |
| DOE-2 | | | 16.0 | 12.0 |
| TC 4.7 | | | 22.7* | 23. |
| AXCESS | | | 19.6 | 49. |
| TC 4.7 | 11.25 | 4.0 | 4.5 | 39.89 |
| TRACE | 11.25 | 2.9 | 2.2 | 20.13 |

*Sum of all the electrical consumption

Table A-4 Summary of ASHRAE RP-205
Comparative Energy Calculation Between the
Hourly Simulation Method and Simplified TC 4.7 Method
For - VAV and 4-Pipe Fan Coil Heat Reclaim Systems

| | Ligih Equip $kW/yr/ft^2$ | Fan $kW/yr/ft^2$ | Cooling Plant $kW/yr/ft^2$ | Heating Gas $cf/yr/ft^2$ |
|---|---|---|---|---|
| TC 4.7 | 11.1 | 3.0 | 6.3 | 20.1 |
| E-CUBE-III | 11.1 | 2.8 | 5.4 | 20.4 |
| TC 4.7 | 11.8 | 11.5 | 9.3 | 170.2 |
| ESAS | 11.8 | 9.2 | 8.1 | 140.8 |
| TC 4.7 | 12.6 | 1.4 | 4.3 | 27.68 |
| BLDSIM | 12.6 | 2.4 | 2.9 | 11.22 |
| TC 4.7 | 11.7 | 2.4 | 4.51 | 12.40 |
| BLAST | 11.2 | 2.6 | 4.43 | 10.85 |
| TC 4.7 | | | 17.3* | 5.1 |
| DOE-2 | | | 16.0 | 9.9 |
| TC 4.7 | | | 23.* | 4.16 |
| AXCESS | | | 25.1 | kWh/ft 0 |
| TC 4.7 | 11.25 | 4.0 | 4.45 | 13.82 |
| TRACE | 11.25 | 2.9 | 2.65 | 19.60 |

*Sum of all the electrical consumption

Table B
Comparative Energy Calculation Between the ASHRAE TC 4.7
Simplified Method and Hourly Simulation Method Performed for
Very Complex and Larger Building under DOE/AIA Reserach Program

Results of DOE/AIARC Studies

| | | Light Equip | Fans | Cooling | Heating | Hot Water |
|---|---|---|---|---|---|---|
| Office Bldg. (heat pump) | AXCESS | 14,408 | 7,913 | 8,668 | | |
| | DOE-1 | 13,910 | 8,230 | 7,907 | | |
| | BLAST | 13,997 | 10,256 | 8,569 | | |
| | TC 4.7 | 14,604 | 5,996 | 9,648 | | |
| Hospital | AXCESS | 25,580 | 59,835 | 68,575 | 30,363 | 2,763 |
| | DOE-1 | 20,532 | 59,893 | 66,619 | 51,994 | 2,608 |
| | BLAST | 24,386 | 62,485 | 69,210 | 64,495 | 2,807 |
| | TC 4.7 | 26,011 | 66,486 | 47,329 | 49,373 | 2,922 |
| Store | AXCESS | 21,345 | 8,558 | 4,885 | 1,960 | 5,007 |
| | DOE-1 | 21,228 | 8,386 | 3,760 | 4,328 | 4,950 |
| | BLAST | 21,414 | 9,925 | 6,216 | 1,628 | 6,668 |
| | TC 4.7 | 20,934 | 9,706 | 4,833 | 165 | 4,987 |
| Warehouse | AXCESS | 5,606 | 740 | 720 | 32,134 | 426 |
| | DOE-1 | 6,370 | 1,420 | 37 | 21,460 | 412 |
| | BLAST | 5,237 | 1,021 | 344 | 40,451 | 415 |
| | TC 4.7 | 5,429 | 960 | 592 | 18,311 | 427 |

*This particular table is not the result of RP-205, but was done under a separate study conducted by the AIA Research Corporation for larger complex buildings.

Table C

Man/hours Report by the RP-205 Participants for the Learning and Completion of the TC 4.7 Simplified Energy Analysis Procedure

| RP-205 Participants | Learning | Calculation for 4 HVAC systems | Total man/hour to complete the list |
|---|---|---|---|
| Dr. E. Knebel (BLAST) | 32 | 84 | 116 |
| G. K. Yuill (ESAS) | | | 431.5 |
| G. Reeves (AXCESS) | minimal | 65 | 65 |
| J. Patel (BLDSIM) | 16 | 137 | 153 |
| D. P. Deyoe (ECUBE) | 112 | 240 | 352 |
| C. L. Ringquist (TRACE) | 50 | 270 | 320 |
| M. Lokmankikin (DOE-2) | extremely time consuming | easy/straight forward | 4-5 time of DOE-2 efforts |