THE INTERACTION OF BUILDING LIGHTING AND HVAC SYSTEMS

by

Jay P. Conniff, PE
Vice President
Ross & Baruzzini, Inc.
1304 Baur Boulevard
St. Louis, MO 63132

Robert A. Rundquist, PE
Owner
R A Rundquist Associates Inc.
56 Ward Avenue
Northhampton, MA 01060

ABSTRACT

Over the past 5 years, Dubin-Bloome Associates (DBA) and Ross & Baruzzini, Inc. (R&B) have jointly been working on a project to determine the relationship of the air conditioning load caused by building lighting with time. Our effort has been funded by the Electric Power Research Institute.

An initial literature search determined that the basis of existing calculation methods was data generated by Mitalas in the 1950's for a very limited set of experiments. DBA and R&B then embarked on an experimental program with National Institute of Standards and Technology (formerly National Bureau of Standards) to more fully investigate variables which might effect the load vs time relationship in present-day buildings. NIST has been funded by The Department of Energy (DOE) for their portion of this effort.

This paper presents simulation results calculated by several programs, DOE 2, BLAST, Carrier's HAP and Trane's TRACE and MicroAXCESS. These are compared with test results generated by NIST. A discussion of the simulation techniques and the variables which affect the simulation results is included for each of the programs.

The simulations show that four of the programs track the experimental results very closely. However, three of these programs use the weighting factor method developed by Mitalas. This method is not well suited to simulation of the demand reduction strategies proposed.

INTRODUCTION

Over the past several years, a team from Ross & Baruzzini, Inc. and Dubin-Bloome Associates has been working on a project funded by the Electric Power Research Institute to study the interaction of building lighting and HVAC systems.

In 1986, we joined forces with NIST, who is funded by DOE, to build a full scale model of an interior space in an office building. The model has been carefully instrumented and over 200 tests have been run to study the variables in the interaction. Figure 1 shows the test room which is located at NIST in Gaithersburg, Maryland.

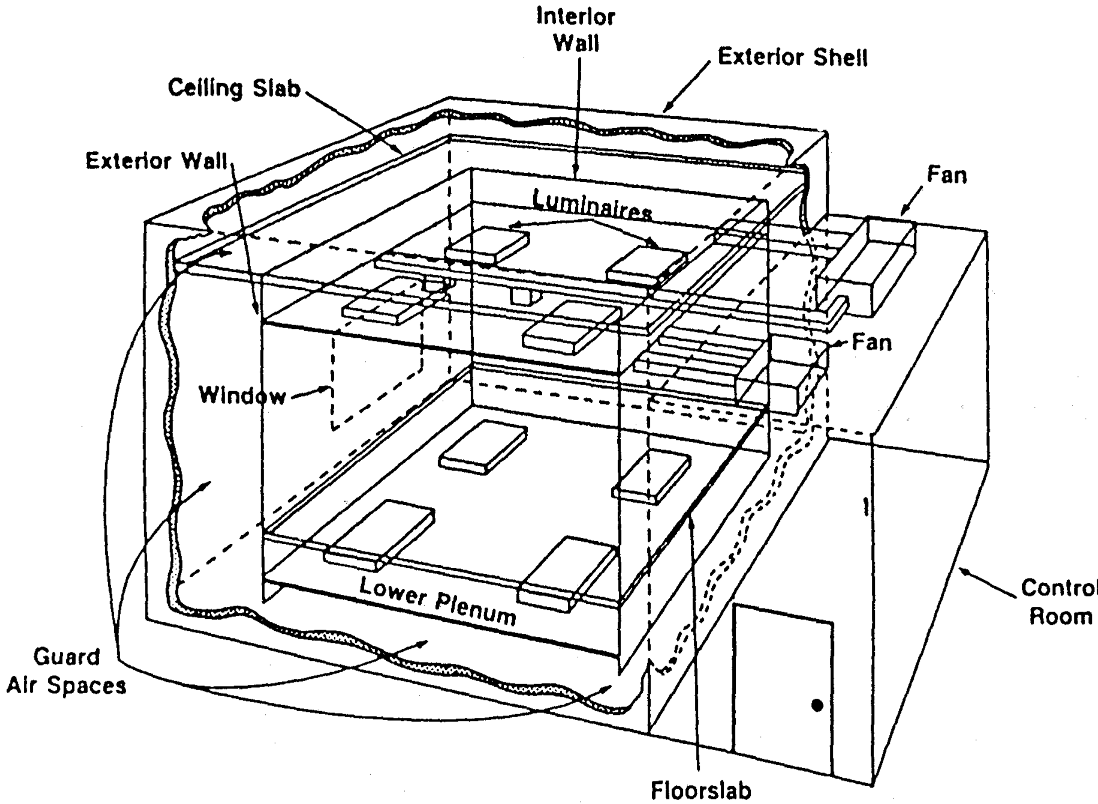

Figure 1
Lighting/HVAC Test Facility

In addition to testing, we have made a study of the more popular methods used to calculate the interaction. This paper will discuss five popular computer programs which model building HVAC and lighting interaction, discuss the techniques used in each program and compare computer simulations from each program to test data.

The five programs studied are BLAST, DOE-2, TRACE, HAP and Micro-AXCESS. In general, these programs use three different methods to calculate the interaction. One program, HAP, assumes 100% of light input goes to the HVAC system. Three programs, DOE-2, TRACE and Micro-AXCESS, use a weighting factor method. The remaining program, BLAST, uses a heat balance between room surfaces, room air, and the light fixture to determine the air conditioning load.

All the programs, except HAP, correctly predict the shape of the interaction curve and differ between themselves by only 10% of the lighting input. The test results fall in between, so the programs generally are within 5% of the test results.

Although the simulations are very good in four of the programs, the need to simulate other buildings and operating methods outside the present capabilities of these programs is important. We are trying to find operating methods and construction methods which will allow us to use the heat storage in the building to reduce peak air conditioning loads and therefore, peak electric demand. In order for building design engineers to study these methods and their application to the building which is being designed, simulations of alternates must be performed to determine the cost/benefit ratios.

BLAST

Building Loads Analysis and System Thermodynamics (BLAST) is a program originally developed for the United States Air Force. The program was originally developed for large computers, but is now available in a micro version.

The program contains a space load sub program which calculates the space load by using a heat balance. This program does a complete radiant, convective, and conductive heat balance for each room surface and the room air. The transient heat transfer through walls, and the heat stored in the various elements such as the walls and floor, are accounted for in this program.

This program can handle transient loading such as turning the lights on and off several times per day.

In operation, the program assumes that the fraction of lighting power which goes to the return air plenum is constant. No allowance is made for the heat stored in the light fixture itself which might lead to poor correlation during the first hour when lights are switched on or off.

The program can simulate the plenum as a separate space from the room. In this mode, the radiant heat transfer from the light fixture to other surfaces in the plenum is calculated. The heat from the light fixture to the plenum air is convective. Additionally, each surface in the plenum convects heat to or from the return air.

BLAST performed simulations which tracked the test data very closely. These are illustrated in Figures 2 and 3. In addition to good agreement individually, BLAST correctly predicted the effect of changing air flow.

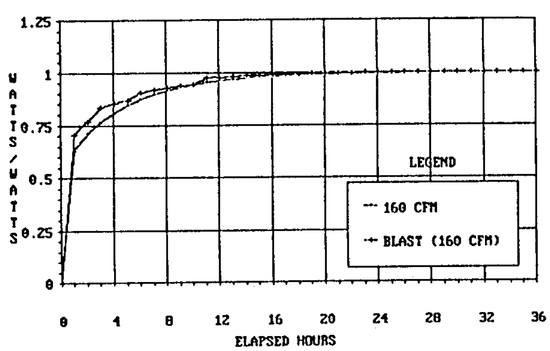

Figure 2: BLAST vs Test at 160 CFM

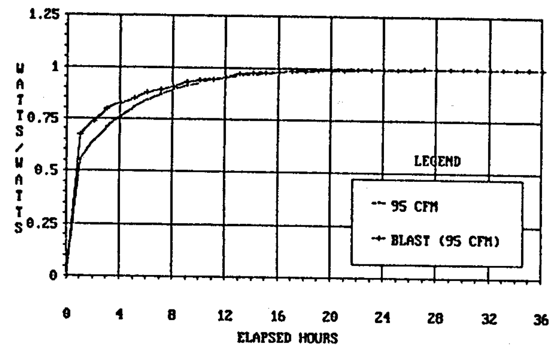

Figure 3: BLAST vs Test at 95 CFM

The air flow is considered constant volume in this program and does not influence the convection coefficients, or the heat stored in the room, but will influence the heat stored in the plenum elements, since plenum temperature will change with air flow.

The heat stored in the room walls and the heat transfer through the ceiling vary with air flow because of changes in surface convection. These effects are illustrated in Figures 3 and 4. BLAST does not change convection coefficients so these influences are lost.

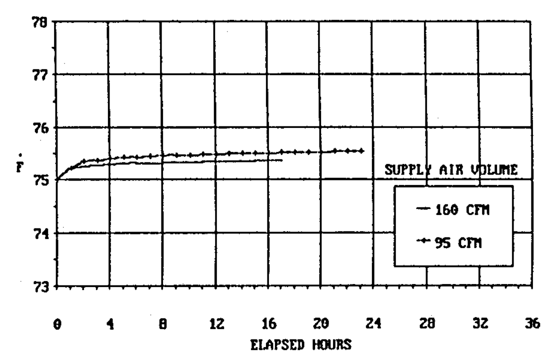

Figure 4: Wall Surface Temp. Per Test

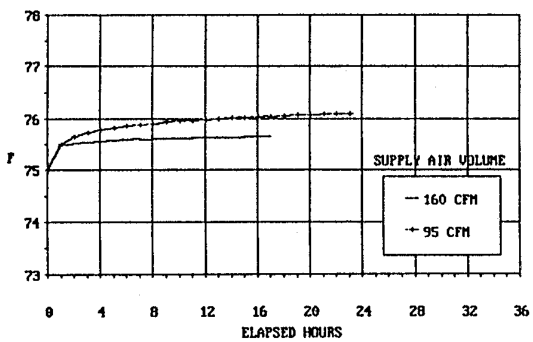

Figure 5: Ceiling Surface Temp. Per Test

Many BLAST simulations are run without modeling the plenum as a separate space. When this occurs the curve of load vs time is as shown in Figure 6. This could lead to substantial errors up to five or more hours after the lights are turned on.

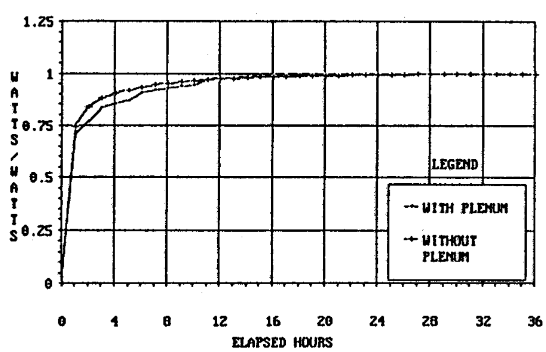

Figure 6: BLAST With & Without Plenum

DOE 2

DOE 2 was developed for the Department of Energy. The program was originally developed for large computers, but is now available in a micro version.

The program contains a space load sub program which uses weighting factors to determine the heat from lights. Weighting factors can be chosen from a table by specifying floor weight and type of light fixture, or may be calculated in a special subroutine which considers room geometry as well as construction of walls, ceilings and floors. The weighting factors are not adjusted for air flow in either case.

DOE 2 considers the plenum as a separate space. The user inputs a plenum temperature during the space loads calculation. During the systems portion, the program calculates the return air temperature (assumed to be the same as plenum temperature) and air flow. The program then adjusts the heat transfer through the ceiling to the room to allow for the calculated temperature difference.

DOE 2 demonstrates close agreement with the test data for both methods of calculation as shown in Figures 7 and 8. However, DOE 2 did not predict any change in air conditioning load with air flow.

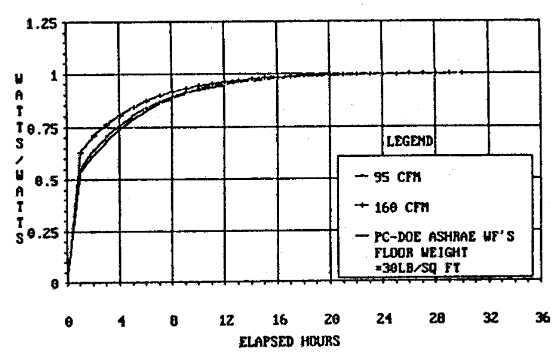

Figure 7: DOE 2 vs Test

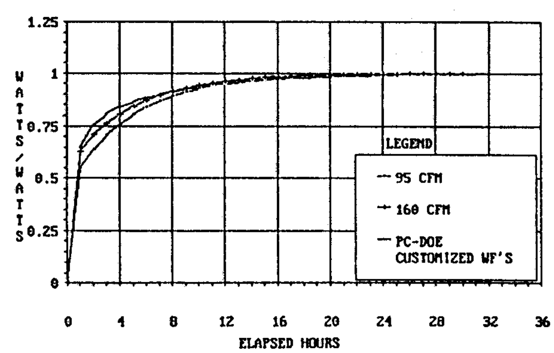

Figure 8: DOE 2 vs Test Custom Weighting Factors

TRACE ULTRA

TRACE ULTRA is the Personal Computer version of TRACE 500, the earlier mainframe version.

TRACE loads are calculated for one typical day per month, for three day types (weekday, Saturday, and Sunday). Three identical weekdays are run to approach steady-state, followed by a weekend. Peak day loads are also calculated each month.

Total lighting transient heat-gain is calculated from ASHRAE weighting factors, as interpolated for building mass (but not for airflow, etc.). Inputs include fraction lighting heat upward, return air path, percent lighting heat to return air (at design), room classification and air circulation (same categories as for ASHRAE a1 and b1 factors), ceiling tile R-value, and VAV parameters.

In the loads section, plenum conditions are calculated based on air flow, light heat up, and ceiling tile resistance. Here, lighting heat to return air is assumed fixed at its input design value. Also in the Design section, supply air dry bulb is calculated to satisfy room load.

The following can effect plenum load: ceiling conduction, return air flow, roof conduction, adjacent plenum conduction, skylight solar, cool bypass air, runaround airflow, and optional ventilation air. Heat flow through floor slab to another space is not considered. This may lead to an error if the floor resistance is not much higher than the ceiling. The program would not correctly predict the effect of carpeting, which we have found to be an important variable.

Possible return air paths are ducted, plenum, corridor, and plenum-then-corridor.

TRACE also does a good job of predicting the air conditioning load as shown in Figure 9. However, TRACE does not predict the effect of changing air flow, for the air flows treated here.

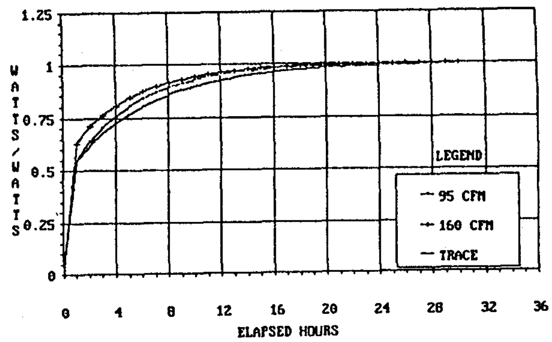

Figure 9: TRACE vs Test

HAP

Carrier's Hourly Analysis Program (HAP) was developed from the Carrier load calculation procedure. The program contains a space load sub-program, which is essentially the hand load calculation method. It uses 100% of the lighting input to calculate the air conditioning load due to lighting for each hour. This is presented graphically in Figure 10.

Carrier has no provision for the effects of step load changes or other unusual operating procedures.

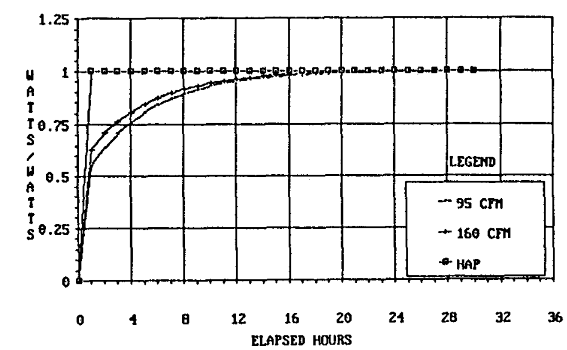

Figure 10: HAP vs Test

Micro-AXCESS

Micro-AXCESS is a microcomputer version of AXCESS Energy Analysis program (Version 8.1) originally developed and released by Edison Electric Institute. Siska & Hennessy in New York currently markets Micro-AXCESS version 8.2 and 8.2.1. Version 8.2.1 includes a menu-driven input editor.

Loads are calculated 8760 hours per year, or the user can skip to calculating every fifth day. However, the current version (8.2 or 8.2.1) has available as output only monthly total and peak energy consumption, divided between fuel types and meters as defined by the user. Siska & Hennessy is now developing a new program version, for Electric Power Research Institute, that will also calculate and report out hourly information for peak days.

Transient heat-from-lights is calculated using ASHRAE methodology and weighting factors. Medium airflow is assumed, and the associated ASHRAE "a" value, 0.55, is the only one possible in the calculation. Weight of building is input as either light, medium, or heavy; this defines the ASHRAE w1 value, again for medium airflow only. The current Siska & Hennessy work will not affect these options.

Inputs, in addition to building weight (light, medium, heavy), are fraction lighting heat upward, ceiling tile U-value, supply air CFM per square foot, and VAV parameters.

Return air path is assumed to be through the plenum, and airflow does not influence the fraction of lighting heat upward. Heat to the plenum is the sum of lighting heat upward and envelope gain/loss through the plenum portions of exterior walls. Plenum temperature for the calculation of envelope gains/losses is taken as the previous hour's value. The plenum heat gain thus calculated is used with the input CFM to calculate a temporary value of plenum temperature. From this, heat flow through the ceiling to the room is calculated and used to correct the plenum heat gain and temperature (without iteration) to values for the hour. Micro-AXCESS also shows good agreement between test data and the simulation. This is illustrated in Figure 11.

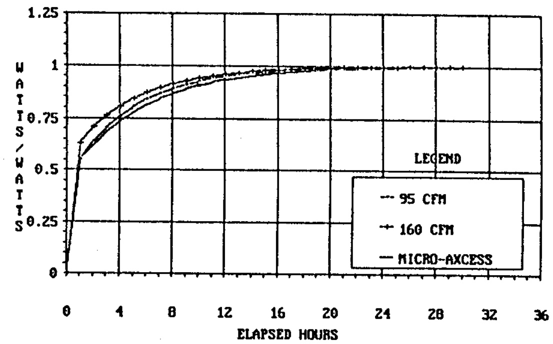

Figure 11: Micro-AXCESS vs Test

DEMAND REDUCTION

The following Demand Reduction strategies will be studied in the future work of our program:

- Varying lighting loads.
- Switch return air from ceiling and ducted.
- Let temperature drift up during peak load hours.
- Precool room.
- Insulate floor and ceiling to increase heat storage in the plenum.
- Cool plenum for part of the day to reduce peak load.

CONCLUSION

The programs studied for this paper all do a good job of tracking the test with the exception of HAP. The test case was similar to the cases studied by Mitalas which the programs were designed to track, so this result was expected. However, a closer look at the variables considered and the method of calculation indicated that only BLAST was well suited to studies of operating procedures which were not the test procedure.