COMPARISON OF FOUR VERSIONS OF THE DOE-2 ENERGY ANALYSIS PROGRAM

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ABSTRACT

In the last five years, four new versions of the DOE-2 building energy simulation program have been released on a regular basis by Lawrence Berkeley Laboratory -- DOE-2.1, DOE-2.1A, DOE-2.1B, and the most recent, DOE-2.1C. In this paper, the variation in results from these four versions of DOE-2 are compared and contrasted for three example office buildings in five locations in the Tennessee Valley region. Variations in annual total and component building energy performance, and the possible reasons for the variances are discussed. Variation in predicted building and plant peak loads are also shown.

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INTRODUCTION

During the development of Energy Design Guidelines for Offices, the Tennessee Valley Authority (TVA) conducted a study of the effects of location and building size on building energy performance and loads. In this study, three example office buildings were analyzed using DOE-2.1 to demonstrate these variations in the Tennessee Valley region. TVA used three of the buildings in further unpublished supplementary studies of the differences among versions of DOE-2. Initial analysis was conducted using DOE-2.1, with follow-up analysis using both DOE-2.1A and DOE-2.1B. This work was recently extended by Pacific Northwest Laboratory (PNL) to include comparisons with DOE-2.1C. Analysis was conducted for five locations: Asheville, NC; Chattanooga, TN; Jackson, MS; Memphis, TN; and Nashville, TN using TMY (Typical Meterological Year) weather data for each location. The site data for the five TMY locations are summarized in Table I.

The reader is cautioned that this paper only presents a case study of one building type, with a single HVAC system. The results presented here cannot be generalized for other locations, building types, or systems.

BUILDING DESCRIPTIONS

The buildings are hypothetical examples of well-designed office buildings in the Tennessee Valley. The buildings were not intended to be examples of super-energy-efficient buildings but rather they were to be reasonable design solutions that would demonstrate the impacts of size and climatic variations in that region. The buildings range in size from three story, 54,000 ft^2 (Building 1), to three story, 104,580 ft^2 (Building 2), and twenty story, 450,000 ft^2 (Building 3). Schematic perspectives of the three buildings are shown in Figure 1.

The buildings were simulated with the Standard Building Operating Conditions (SBOC) from the proposed Building Energy Performance Standards (BEPS), assuming typical office operation from 8:30 am to 5:30 pm, five days per week. Occupancy density was set at 250 ft^2 per person. Ventilation air was set at 15 CFM per person. A configuration for building envelope was selected to comply with ANSI/ASHRAE/IES Standard 90-75, the energy code for the five locations considered. Air delivery was simulated as variable air volume systems with plenum return. Temperature setpoints of 70°F heating and 75°F cooling were used. Night setback and setup temperatures were simulated as 60°F and 80°F respectively. Standard efficiency (DOE-2 default) open-drive centrifugal chillers and natural gas-fired hot water boilers were simulated as primary plant equipment. Lighting systems were simulated as fluorescent recessed fixtures, with an average 1.6 W/ft^2 power density. Average miscellaneous office equipment was simulated at 0.5 W/ft^2 power density.

DOE-2 VERSIONS

The versions of DOE-2 used in the analyses were:

- DOE-2.1 January 1980 release
- DOE-2.1A February 1982 release
- DOE-2.1B January 1983 release
- DOE-2.1C May 1984 release

The input files for each of the three buildings were identical for the different DOE-2 versions with the following exceptions. The MULTIPLIER command was changed to a FLOOR-MULTIPLIER for the DOE-2.1B and DOE-2.1C simulations. This only affected the largest of the three buildings. In LOADS, only the site data changed between locations. The BASEBOARD-RATINGS in SYSTEMS, and the primary equipment sizes in PLANT were adjusted for the locations based on the DOE-2 calculated loads. The air delivery systems were also automatically sized by DOE-2.

RESULTS

The DOE-2 simulation results for the three buildings in the five locations are compared in a number of ways in the following discussion and Figures:

- Total annual building energy performance, in kBtu/y•ft^2
- Annual heating energy performance, in kBtu/y•ft^2
- Annual cooling energy performance, in kBtu/y•ft^2
- Annual HVAC auxiliaries (fans and pumps) energy performance, in kBtu/y•ft^2
- Peak heating and cooling loads, in Btuh/ft^2
- Peak boiler and chiller plant loads, in Btuh/ft^2

Annual Energy Performance

As can be seen in Figure 2 for Buildings 1, 2, and 3, the annual energy performance varies relatively little -- no more than 5% variation between the four versions of DOE-2 or even between locations in the Tennessee Valley region. The variation is greatest in the smallest building -- Building 1 and less significant in Buildings 2 and 3. On an annual basis, the DOE-2 version has very little impact on total energy performance for these example buildings. In general, for all locations, estimated energy requirements dropped between DOE-2.1 and DOE-2.1A. In most cases, energy requirements increased for DOE-2.1B above that of DOE-2.1 and DOE-2.1A, and then decreased for DOE-2.1C.

Figure 2 compares the simulation results for the total annual energy performance and the end-use components. Two of these end-uses, lighting and other (service hot water, vertical transportation, and miscellaneous equipment), remain constant regardless of the DOE-2 version or location. The following three Figures illustrate the differences encountered in the other three end-use components.

In Figure 3, annual heating energy performance is depicted for the three buildings. As expected, based on the relative Heating Degree Days shown in Table I, Asheville has the highest annual heating energy requirements, followed by Nashville, Chattanooga, Memphis, and Jackson. The trends between DOE-2 versions for heating energy requirements can be summarized as follows. Usually, DOE-2.1A gives higher energy requirements for heating than either DOE-2.1, DOE-2.1B, or DOE-2.1C. Under most conditions in these example buildings, DOE-2.1B predicts the lowest heating energy requirements of the four versions, followed closely by DOE-2.1C, which usually predicts slightly higher heating. The variation between DOE-2 versions is most dramatic in the larger buildings with heating energy reduced by as much as 35% for DOE-2.1C as compared to DOE-2.1 in Asheville and Jackson for Building 3.

The variations in heating energy requirements can be partially explained by the use of the MULTIPLIER keyword in DOE-2.1 and DOE-2.1A. In those versions, the MULTIPLIER did not work correctly with zones of type PLENUM. This caused the gross over-prediction of heating energy seen in Building 3, although heating still remains a small portion of the total.

In Figure 4, annual cooling energy performance is compared for the three buildings. In the two larger buildings, DOE-2.1 always produces the highest annual cooling energy requirements. In Building 1, DOE-2.1B often approximates the cooling energy predicted by DOE-2.1. In Buildings 2 and 3, DOE-2.1C consistently predicts the lowest energy requirement, but for Building 1, it is usually slightly higher than DOE-2.1A. The most consistent variance is the decrease in cooling energy requirements from DOE-2.1 to DOE-2.1A. As will be discussed later, this is at least partially due to a change in the way the program simulated periods during which zone temperatures are in the deadband range.

The most widely varying of the end-use components is annual HVAC auxiliaries (fans and pumps) energy performance, shown in Figure 5. In all cases, DOE-2.1A predicts the lowest annual energy requirements for this end-use component, followed by DOE-2.1 and DOE-2.1C, with DOE-2.1B predicting the highest. The trends shown for HVAC auxiliary energy performance echo those of cooling energy performance shown in Figure 4, except that the variation is more pronounced. Since all of these buildings have greater cooling energy requirements than heating, the HVAC auxiliaries more closely track cooling energy trends.

Peak Building Loads

The next two figures present the building heating and sensible cooling loads from DOE-2 report LS-C. Figure 6 displays the peak building heating load for the three buildings. In all cases, DOE-2.1A predicts a higher peak heating load than do the other versions of DOE-2. The other versions, DOE-2.1, DOE-2.1B, and DOE-2.1C, calculate almost identical peak heating loads for each location and building.

Where the plenum MULTIPLIER problem was corrected (DOE-2.1B), the peak heating loads dropped in a manner similar to the heating energy in Figure 3. The relatively consistent peak load increases between DOE-2.1 and DOE-2.1A can be partially attributed to a change in interpretation of the deadband. DOE-2.1 forced the heat extraction rate to be zero whenever zone temperatures were within the range of the thermostat deadband. This negated the effects of outside air cooling during those periods. Since these simulations involved 18°F deadbands during nights and weekends, the effect was to underestimate the magnitude of zone temperature drops during those periods. Thus, morning warm-up loads were underestimated with that version of the model.

In Figure 7, peak building sensible cooling loads are shown for each case. The trend is for decreasing loads from DOE-2.1 to DOE-2.1A, DOE-2.1B, and DOE-2.1C. All variations are small -- in the range of 0.1 to 8.2%, with the largest decreases in the smallest building.

Some of the slight decreases in peak cooling loads might be attributable to the changes in the solar sky model in both DOE-2.1B and DOE-2.1C. This appears to be plausible since the smallest building, which is most climate dependent, sustains the largest decreases.

Peak Plant Loads

The last two Figures display the peak load data from DOE-2 Report PS-H for the natural gas-fired boiler and centrifugal chillers. Peak boiler plant load is shown in Figure 8. As in Figure 6, the peak boiler loads tend to decrease for the DOE-2 versions, with the highest simulated loads from DOE-2.1 and the lowest from DOE-2.1C. The exception is Building 3 where DOE-2.1A predicts an increased load over DOE-2.1. For Building 3 the predictions of DOE-2.1B and DOE-2.1C are as much as 60% lower, although they remain consistent with each other, due to correction of the MULTIPLIER in DOE-2.1B as discussed later.

In Figure 9, the peak cooling plant load for the chillers is shown. These loads echo cooling energy more than peak building sensible cooling loads since the effects of ventilation, latent loads, and part load efficiency affect total cooling energy requirements but are not included in the sensible loads shown in Figure 7.

SUMMARY

Heating, cooling and HVAC auxiliaries (fans and pumps) energy performance varies widely between versions and locations due to a number of changes in the DOE-2 algorithms. Variation in heating energy performance is as much as

55%; cooling energy performance 26%; and HVAC auxiliaries 13%. The most significant changes affecting these example buildings are described below.

Changes from DOE-2.1 to DOE-2.1A

- DOE-2.1 forced the heat extraction rate to be zero whenever the zone temperature was within the thermostat deadband range. This tended to negate "free" cooling effects of outside air, and introduced "ghost" heating that kept space temperatures above the setback temperature at night. By correcting this deadband misinterpretation, cooling loads tend to decrease and heating loads tend to increase, and the morning warmup load becomes the peak heating load in the buildings. Effects of the deadband control changes are reflected in the energy performance for heating and cooling shown in Figures 3 and 4, as well as the peak building heating and boiler loads shown in Figures 6 and 8, respectively.

- DOE-2.1 failed to adjust the air quantities for altitude when performing the heating, cooling, and fan energy requirement calculations. This was corrected in DOE-2.1A. For these locations, this slightly reduces fan (Figure 5) and cooling (Figure 4) energy requirements and increases heating (Figure 3) energy requirements.

Changes from DOE-2.1A to DOE-2.1B

- The solar model was changed from an isotropic sky model to an anisotropic sky model with non-uniform distribution of diffuse solar radiation. The impacts of this change are uncertain but from the DOE-2 analyses described in this paper, it appears that the hour and magnitude of peak cooling loads has slightly shifted.

- In DOE-2.1A and DOE-2.1, plenum loads are incorrectly predicted when multipliers are used. The effect is seen first in the SYSTEMS portion of the simulation. DOE-2.1B corrects this problem and introduces a new keyword, FLOOR-MULTIPLIER, that also corrects the ambiguities related to interzonal heat transfer.

Changes from DOE-2.1B to DOE-2.1C

- The algorithm that computes the diffuse component of solar radiation on building surfaces was changed to more accurately correlate the diffuse component of the sun and the amount of cloud cover. The DOE-2 Reference Manual Supplement DOE-2.1C reports that this will cause a significant drop in the peak solar gain for windows as compared to previous versions.

Conclusions

The version of DOE-2 does not have significant impacts on the annual total energy performance of the three example buildings presented here. The variation is always less than 10% of the total for these three buildings. Further, annual energy performance for lighting, miscellaneous equipment, vertical transportation, and service hot water remains essentially identical between DOE-2 versions and locations. These four end-use energy components exactly reflect the scheduled percentage by day of week and installed load.

However, the version of DOE-2 does significantly change heating, cooling, and HVAC auxiliary energy requirements and peak loads, with differences ranging from 0 to 70%. This can be crucial if DOE-2 is used to evaluate the cost-effectiveness of various heating, cooling, fan, and pump efficiency options or if it is used to size HVAC equipment. Since the variation between heating, cooling, and auxiliaries is inconsistent, the different DOE-2 versions may cause a designer to select different sets of energy-efficient options.

ACKNOWLEDGEMENT

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Table I
TMY Site Data

Location	Latitude	Longitude	Altitude	HDD Base 65°F	CDD Base 65°F
Asheville NC	35.5	82.5	2140	4294	842
Nashville TN	36.0	86.7	590	3756	1661
Chattanooga TN	35.0	85.0	665	3583	1578
Memphis TN	35.0	90.0	263	3207	2067
Jackson MS	32.3	90.0	310	2389	2290

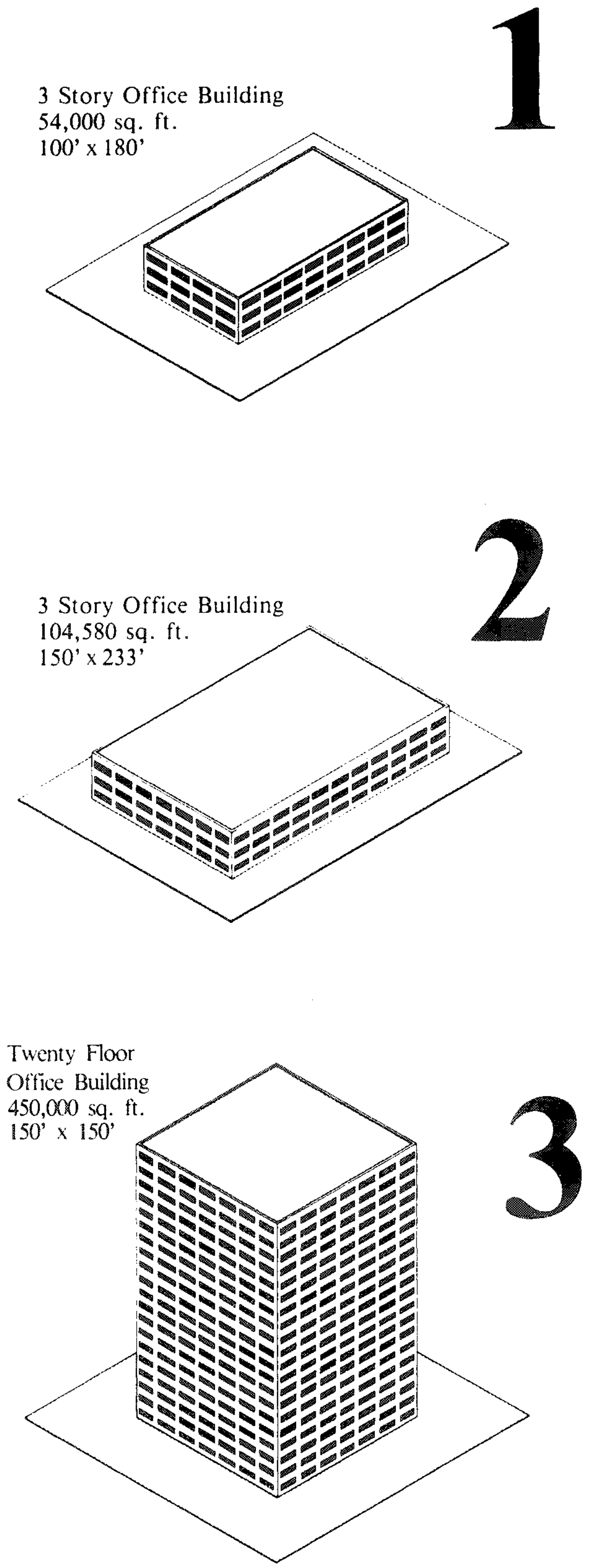


FIGURE 1. Schematic Diagrams of Buildings

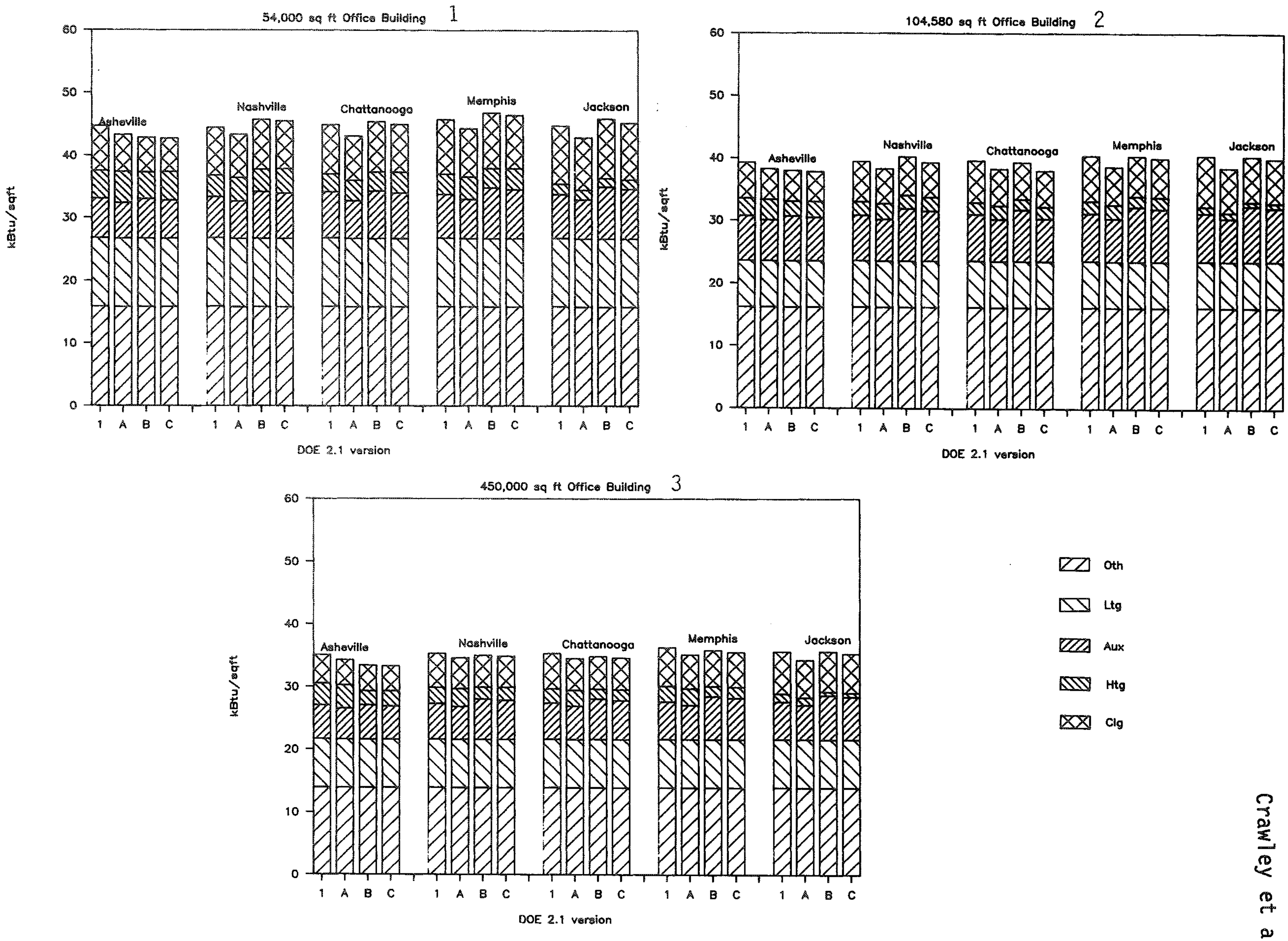
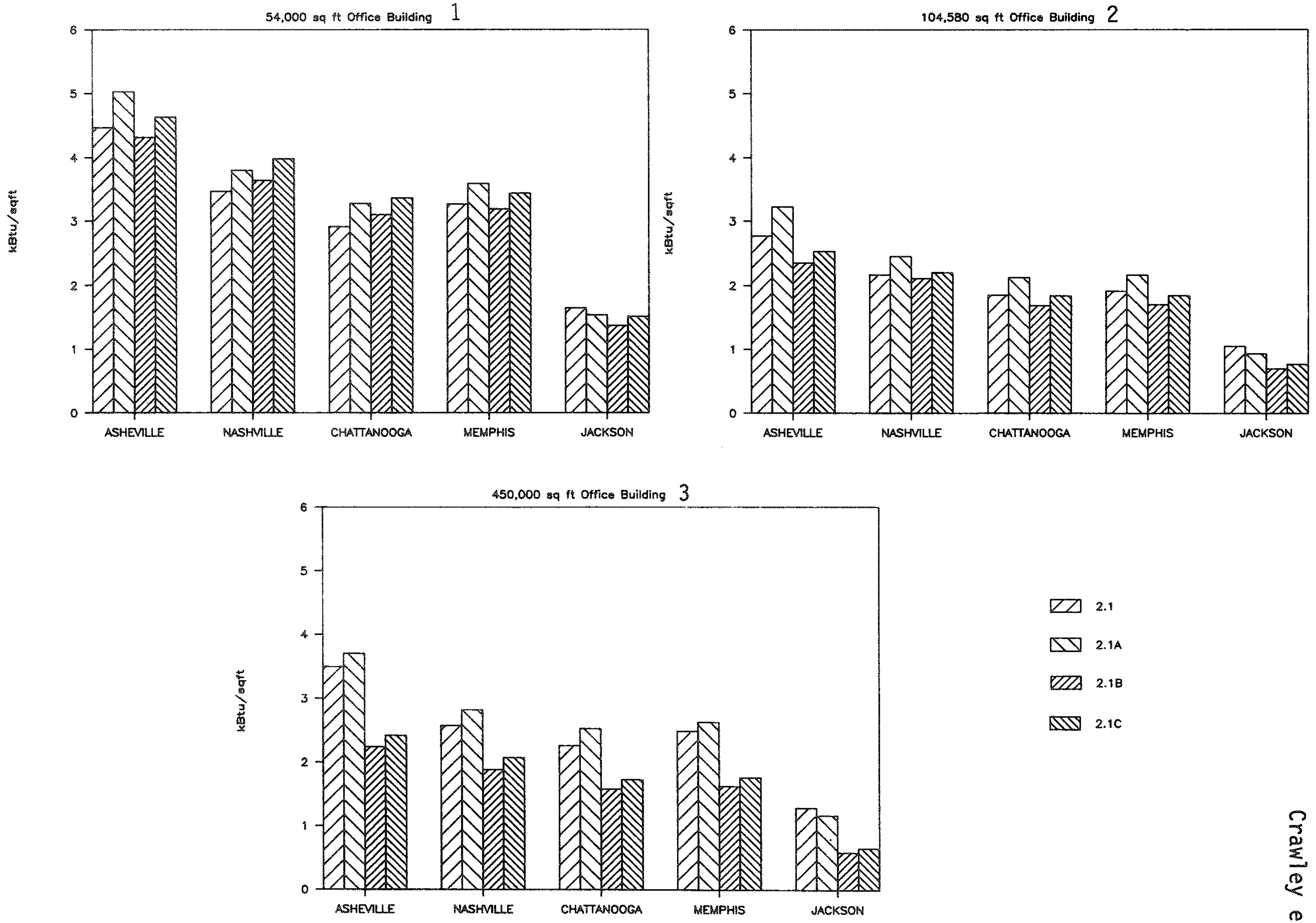


FIGURE 2. Total Annual Energy Performance


54,000 sq ft Office Building 1

104,580 sq ft Office Building 2

450,000 sq ft Office Building 3

FIGURE 3. Annual Heating Energy Performance

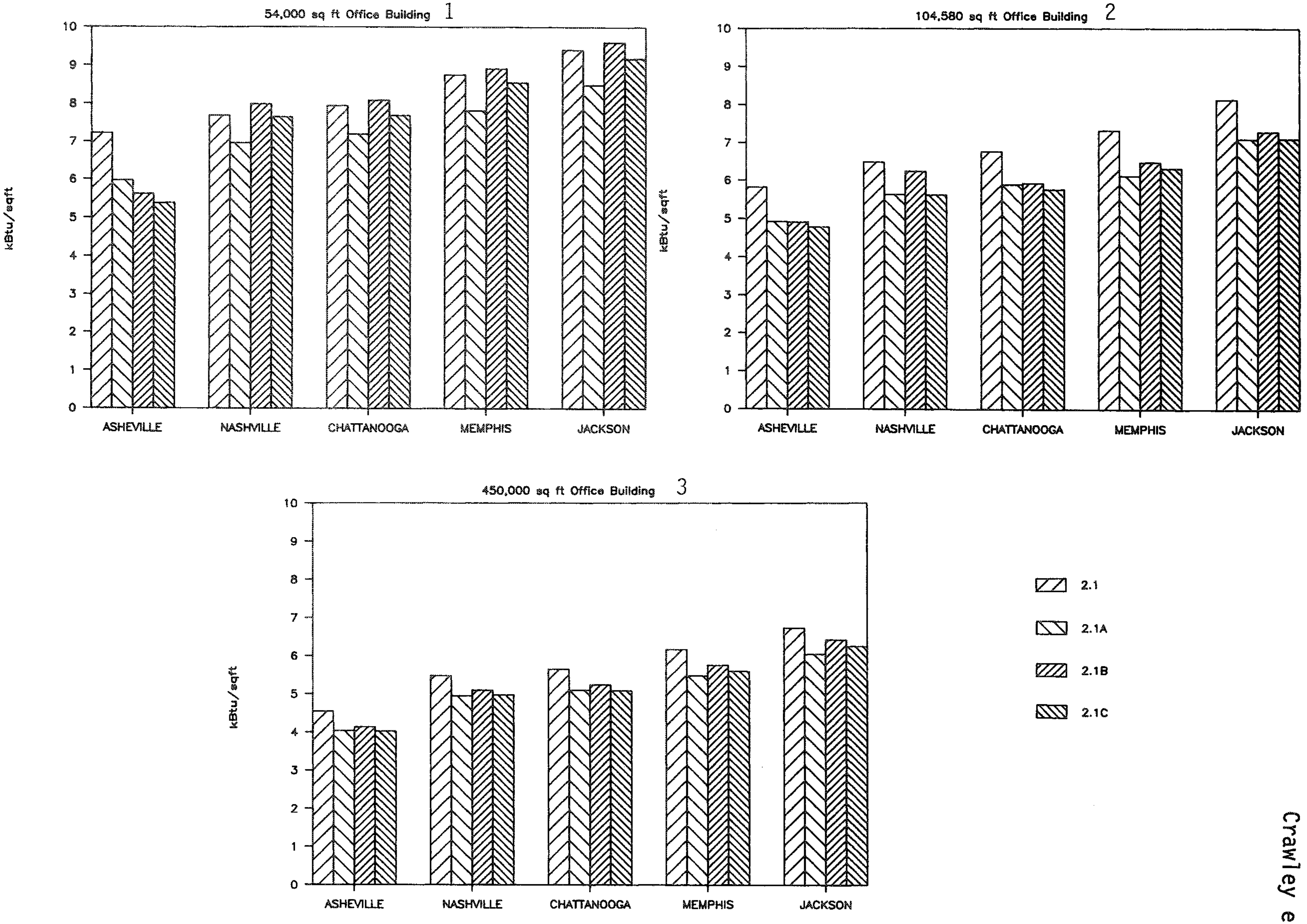


FIGURE 4. Annual Cooling Energy Performance

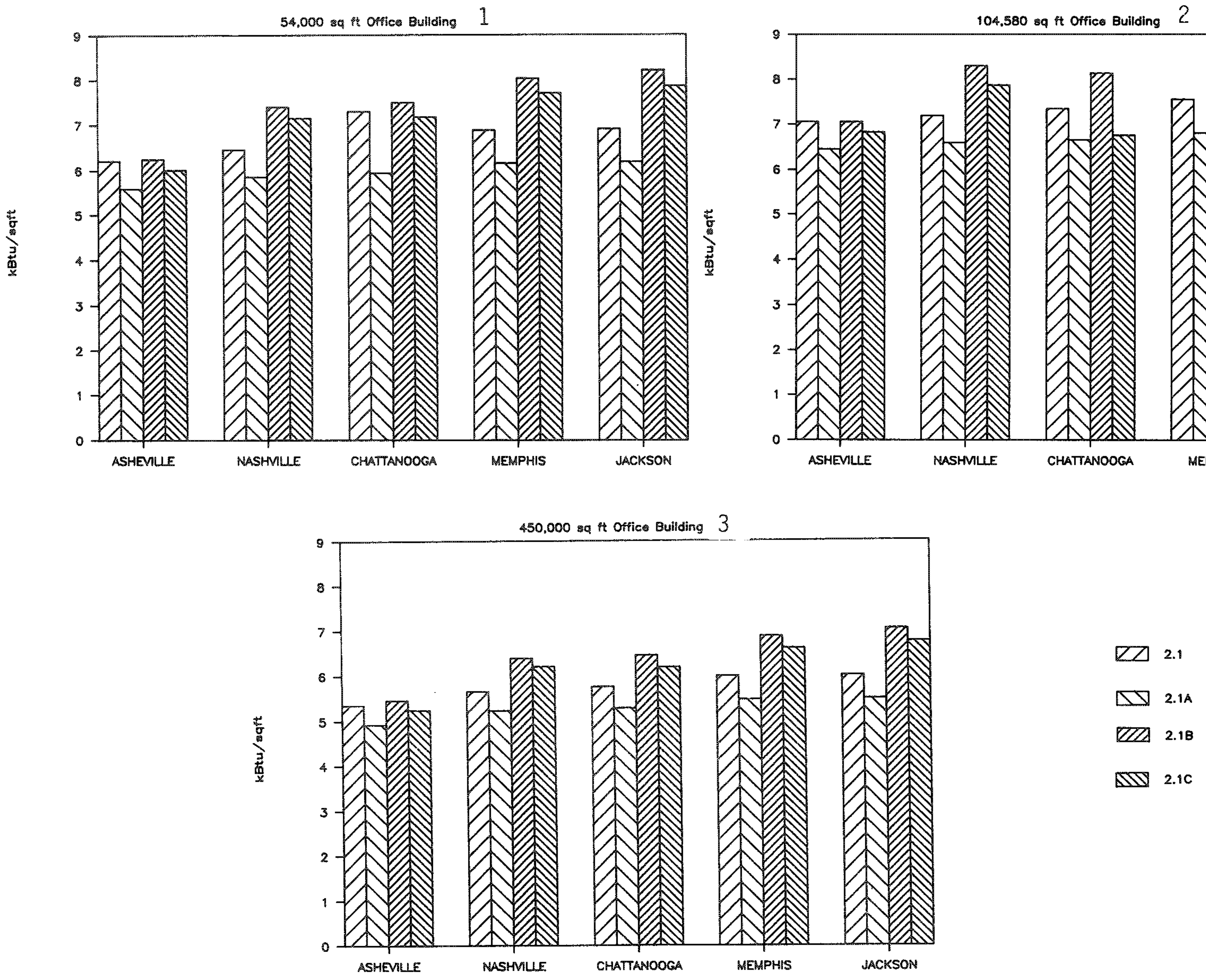
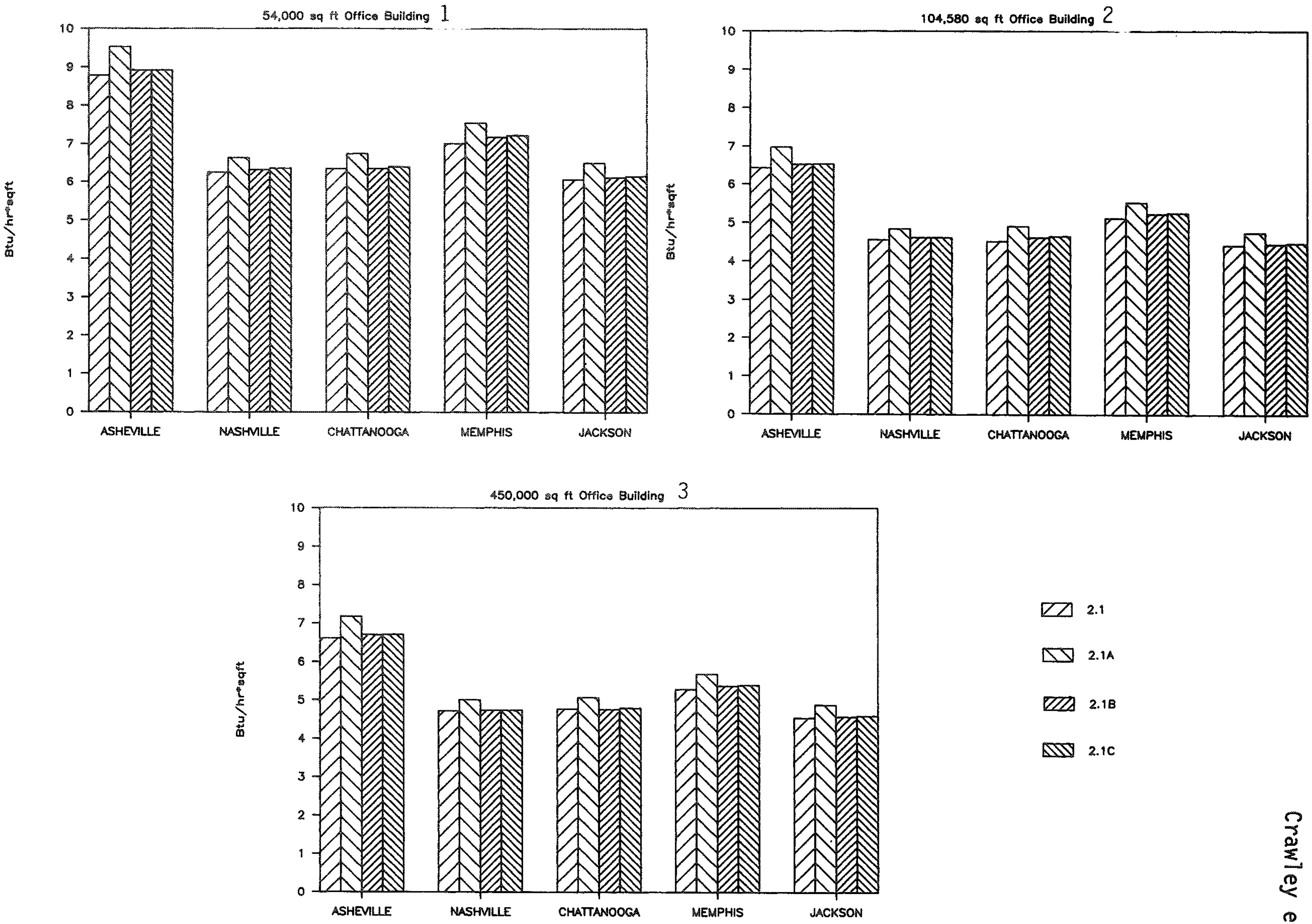


FIGURE 5. Annual HVAC Auxiliaries Energy Performance



<u>FIGURE 6</u>. Peak Building Heating Load

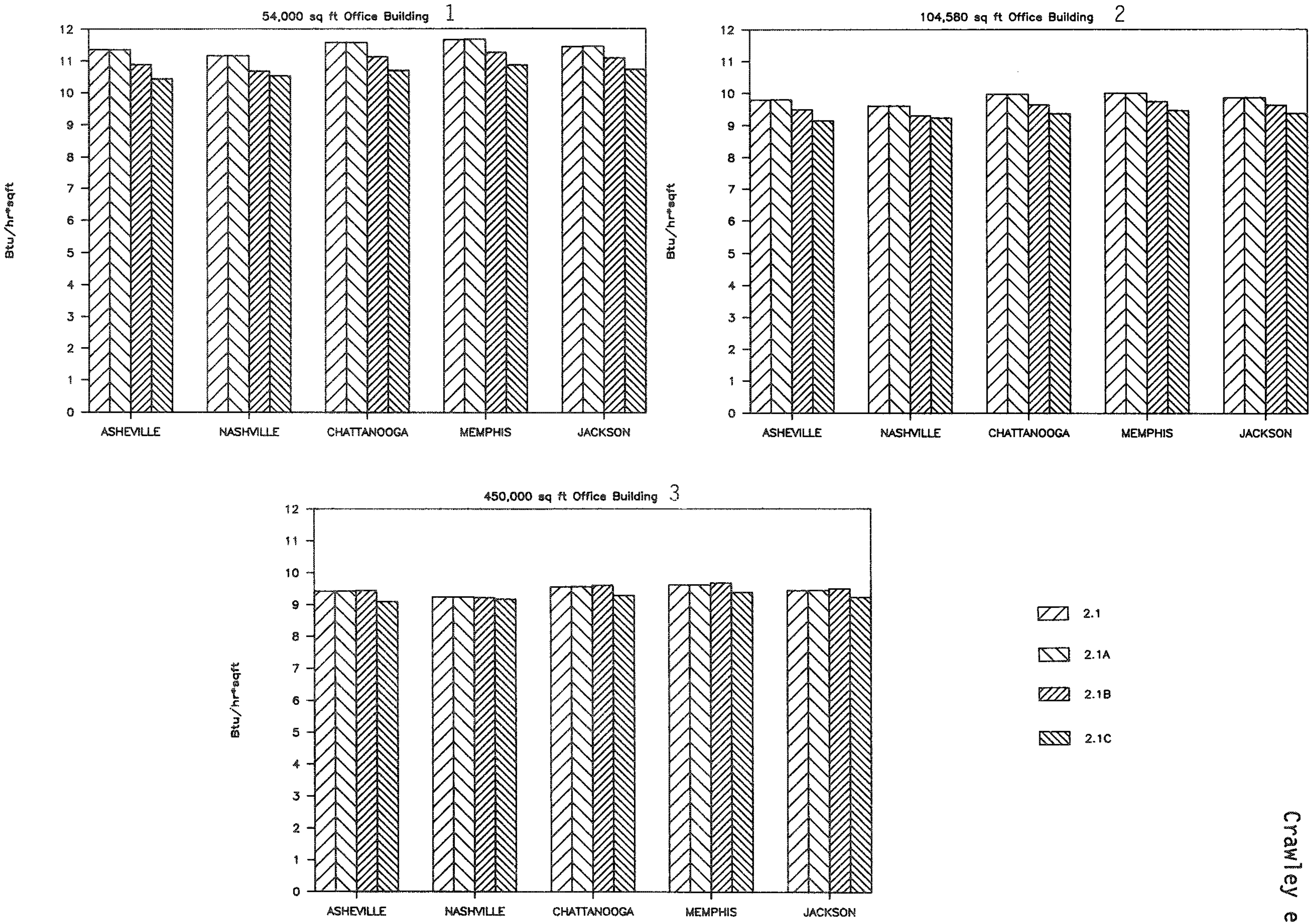


FIGURE 7. Peak Building Sensible Cooling Load

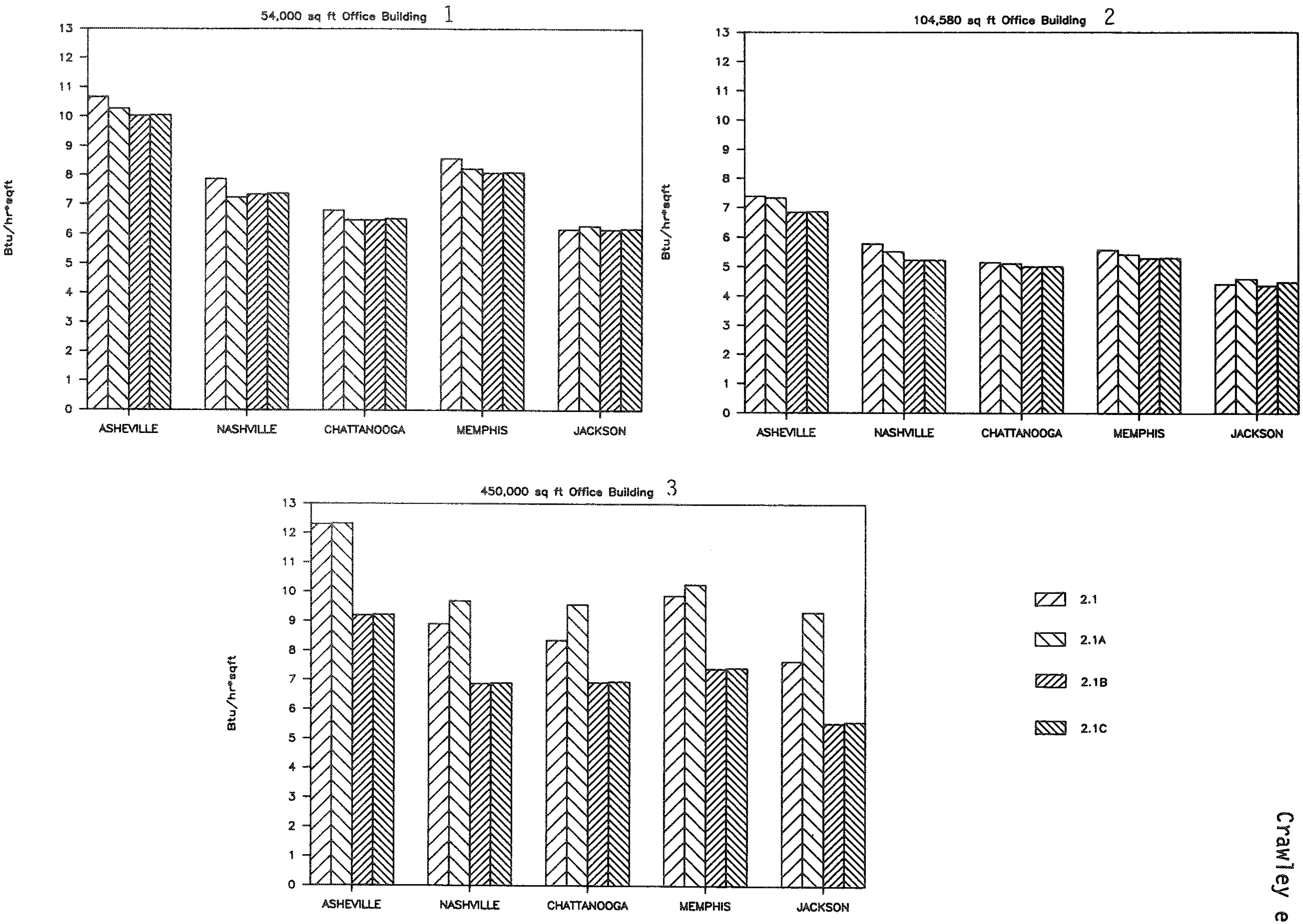


FIGURE 8. Peak Heating Plant Load

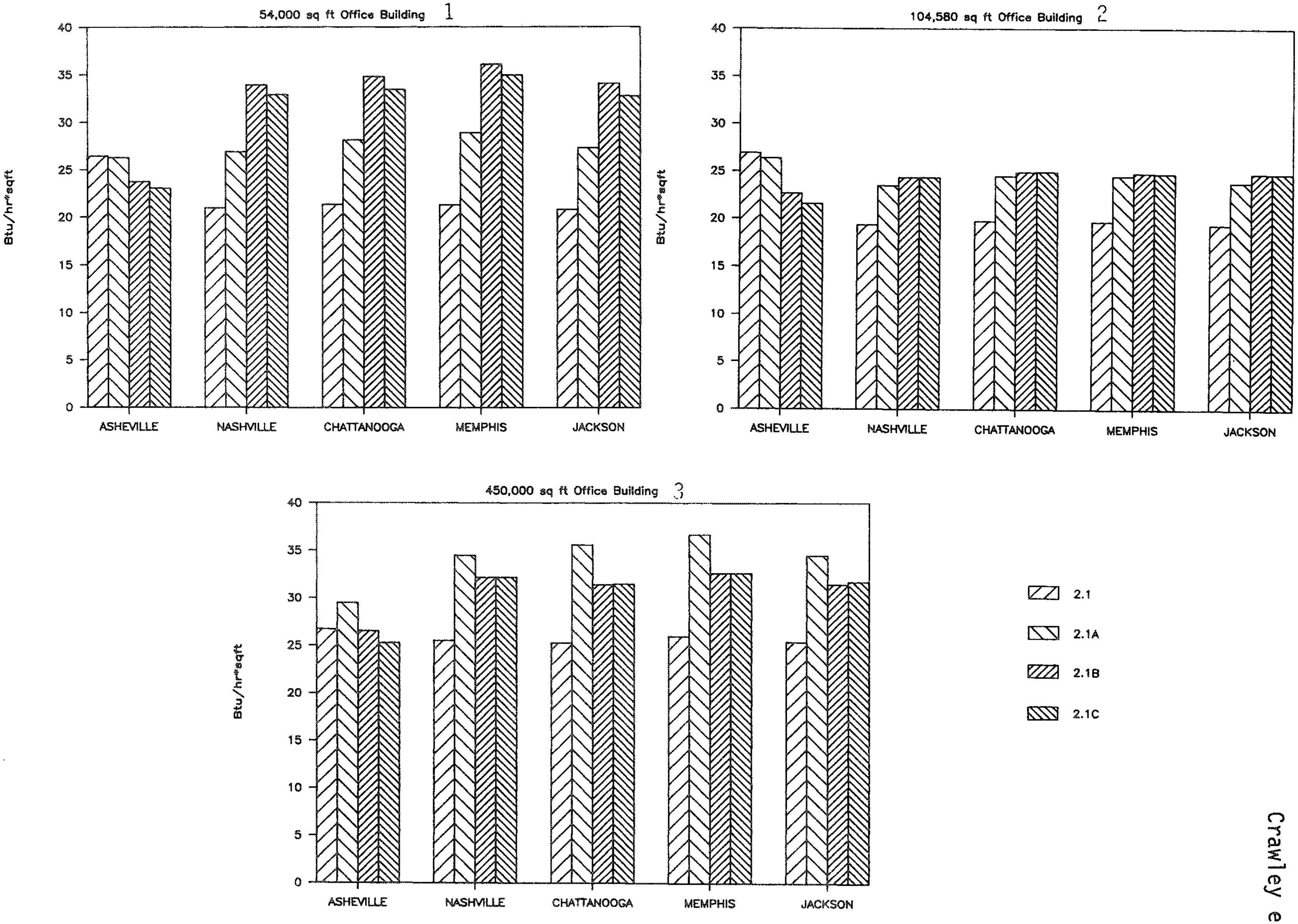


FIGURE 9. Peak Cooling Plant Load