REVIEW OF ANALYSES IN SUPPORT OF PROPOSED U.S. DOE ANOPR ON ENERGY CONSERVATION STANDARDS FOR COMMERCIAL UNITARY AIR CONDITIONERS AND HEAT PUMPS

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EXECUTIVE SUMMARY

The Energy Policy and Conservation Act as amended (EPCA), 42 U.S.C. 6291-6317, establishes energy efficiency standards for certain commercial unitary air conditioners and heat pumps that correspond to ASHRAE Standard 90.1-1992. ASHRAE revised Standard 90.1 in October 1999. Under EPCA, the U.S. Department of Energy (DOE) must determine whether to adopt the new ASHRAE/IESNA Standard 90.1-1999 or more stringent levels of energy efficiency where technically feasible and economically justified (*National Energy Policy Report*, May 2001).

DOE conducted in-depth technical analyses of this matter. To support a more stringent standard than ASHRAE 90.1-1999, the DOE analysis must show that such a standard is technically feasible and economically justified. Some of the elements of this justification are:

- Identifying which facilities will be affected by the proposed rulemaking;
- Determining the electricity consumed by the covered appliances, with and without the proposed rulemaking;
- Estimating the energy and operating cost savings that would result from the standard; and
- Estimating the incremental markup of prices of more efficient air conditioners.

Such analyses require data; assumptions and approximations; analysis procedures, including energy use simulation models; and life cycle cost analysis. This is not a precise process; competent professionals can differ on all aspects of this analysis.

In January 2001, DOE published a final rule adopting ASHRAE/IESNA 90.1-1999 for 18 product categories and decided to further evaluate commercial unitary air conditioners and heat pumps in the range of 65,000 to 240,0000 Btu per hour cooling capacity. In June 2001, DOE published a *Draft Framework Document for Commercial Air Conditioner and Heat Pump Standards Rulemaking*, and solicited public comment. In October 2001, a workshop was held on the proposed rulemaking and public/stakeholder comments. After considering the stakeholder inputs as they related to the technical analysis, DOE decided to assemble an independent review team (IRT) to prepare an independent assessment of:

- Some of the significant comments received, and
- The overall methodology, assumptions, approximations and data used in the Technical Support Document (TSD) for the proposed Advance Notice of Proposed Rulemaking (ANOPR) on Energy Conservation Standards for Commercial Unitary Air Conditioners and Heat Pumps.

In mid-August 2003, DOE contracted with the IRT to evaluate the methods and data used by DOE and comments received in four areas:

1. Assessment of the Buildings Sample Used to Represent Installed Commercial Unitary Air Conditioning Equipment;
2. Comparison of BLAST Simulation and CBECS Estimates of Energy Use in Buildings by Commercial Unitary Air Conditioning Equipment;

3. Commercial Unitary Air Conditioning Equipment Supply Fan Energy Use While Ventilating; and
4. Assessment of the Incremental Markup of Commercial Unitary Air Conditioning Equipment Prices.

Evaluating the Nation's energy use and estimating the effects of proposed rulemaking on that energy use is not an exact science. The IRT's role was not to re-do the DOE analyses but to judge whether they were reasonable and defendable; whether there were errors that should be corrected; and/or whether there were better procedures, data or models to perform the analysis. Where the team concluded that an error had been made or there was a better alternative analysis procedure, we tried, at least qualitatively, to determine whether the proposed modification was likely to significantly affect the results of the TSD.

The analyses by DOE (Headquarters, National Laboratories, contractors, etc.) in the TSD were extensive, following a complex methodology. The IRT took a typical engineering approach to the review: what is wrong and needs to be fixed? This report does not describe all that was, in our opinion, correct and sound, but rather focuses on deficiencies or errors. The IRT approached the task as a "Tiger Team" review of the DOE analysis; we were to point out problems we discovered, with the constructive objective of trouble-shooting the analysis to make it more defendable. (We were not to, and did not, conclude whether the proposed rulemaking was justified.) The IRT concluded that on the whole the DOE analyses were well thought out, logical, comprehensive, and professional.

The IRT analyzed a number of issues, problems or errors in the TSD analysis related to the building sample, BLAST simulations, and the markup analysis.

- The IRT concluded that the stakeholder comments on markups represent a legitimate difference of opinion, but the DOE analysis is basically sound and defendable. Plausible alternative methods and assumptions in the markup analysis and procedures would not significantly affect the results. We recommend that the markup analysis stand as it is.
- The IRT felt that the exclusion of manufacturing sites from the analysis should be further evaluated, as this omission might have a significant effect on the analyses' conclusions.
- For the energy use analysis, the IRT identified several significant errors. Most can be easily corrected (e.g., correcting coefficients in the input data), some will take a bit more effort to correct (e.g., re-segmenting the test buildings' zones to use appropriately-sized A/C). The IRT recommends that these be corrected and the simulations be re-run, as they will likely significantly change the analysis results.
- However, there are serious limitations with BLAST (e.g., outdated compressor models, inability to do part load modeling, the need to validate BLAST rooftop A/C models). Some of these issues (but not all) were identified in the Stakeholder comments.

This report describes the IRT's assessment of these issues, their significance on the validity of the analysis results, and recommendations for addressing them.

1.0 BACKGROUND

The Energy Policy and Conservation ACT (EPCA) as amended, 42 U.S.C. 6291-6317, establishes energy efficiency standards for certain commercial unitary air conditioners and heat pumps that correspond to ASHRAE Standard 90.1-1992. ASHRAE revised Standard 90.1 in October 1999. Under EPCA, the U.S. Department of Energy (DOE) must determine whether to adopt the new ASHRAE/IESNA Standard 90.1-1999 or more stringent levels of energy efficiency where technically feasible and economically justified (*National Energy Policy Report*, May 2001).

DOE conducted in-depth technical analyses of this matter. In January 2001, DOE published a final rule adopting ASHRAE/IESNA 90.1-1999 for 18 product categories and decided to further evaluate commercial unitary air conditioners and heat pumps in the range of 65,000 to 240,0000 Btu per hour cooling capacity. In June 2001, DOE published a *Draft Framework Document for Commercial Air Conditioner and Heat Pump Standards Rulemaking*, and solicited public comment. In October 2001, a workshop was held on the proposed rulemaking and public/stakeholder comments.

Stakeholder input was received, including comments from the Air-Conditioning and Refrigeration Institute (ARI), American Council for an Energy Efficient Economy (ACEEE), Natural Resources Defense Council (NRDC), Lennox, and Trane. After considering the stakeholder inputs as they related to the technical analysis, DOE decided to assemble an independent review team (IRT) to prepare an independent assessment of:

- Some of the significant comments received, and
- The overall methodology, assumptions, approximations and data used in the technical support document (TSD).

This report represents that review of the analyses performed in support of the DOE Advance Notice of Proposed Rulemaking (ANOPR) on Energy Conservation Standards for Commercial Unitary Air Conditioners and Heat Pumps, and some of the comments received by DOE. In mid-August 2003, DOE contracted with the IRT to evaluate the methods and data used by DOE and comments received in four areas:

1. Assessment of the Buildings Sample Used to Represent Installed Commercial Unitary Air Conditioning Equipment;
2. Comparison of BLAST Simulation and CBECS Estimates of Energy Use in Buildings by Commercial Unitary Air Conditioning Equipment;
3. Commercial Unitary Air Conditioning Equipment Supply Fan Energy Use While Ventilating; and
4. Assessment of the Incremental Markup of Commercial Unitary Air Conditioning Equipment Prices.

2.0 SCOPE OF ANALYSIS AND TERMS OF REFERENCE

The IRT was headed by Sentech, Inc. and consisted of five companies and four consultants:

- Energetics, Inc. (Energetics) (James Lyons, P.E.)
- George Reeves Associates, Inc. (GRA) (George Reeves)
- McNeil Technologies, Inc. (McNeil) (Kevin DeGroat, Jack Whittier)
- Princeton Energy Resources International (PERI) (Allan Evans, Ph. D., P.E.)
- Sentech, Inc. (Sentech) (Lawrence Markel)
- Consultants: Dennis L. O'Neal, Ph.D., P.E.; Jerry Jackson, Ph. D.; John Bryant, Ph. D., P.E.; Michael Davis, EIT

Each of the four areas referenced in Section 1.0 was assigned to one group:

1. Buildings sample used for the analysis – Energetics
2. BLAST modeling of building energy use and air-conditioner performance – Consultants, directed by Dennis O'Neal under contract to Sentech
3. Modeling of ventilation and fan use – Consultants, directed by Dennis O'Neal under contract to Sentech
4. Incremental markup of A/C pricing – McNeil

Overall technical review, coordination, and supplemental technical analysis were provided by Sentech, with support from GRA and PERI.

The IRT recognizes that evaluating the Nation's energy use and estimating the effects of proposed rulemaking on that energy use is not an exact science. There is not a unique "correct" method to perform this analysis. Reasonable and competent analysts may differ on techniques, data, assumptions, and approximations used. The objectives of this independent analysis were to review the DOE ANOPR analyses and to evaluate the approach, assumptions, data, models/software, and engineering judgments used, to determine if they are reasonable, logical and defendable.

The IRT was not tasked to re-do or duplicate the original analyses. It was not supposed to come up with the "answer," but to determine whether the underlying analyses and/or the issues raised in the comments DOE has received are valid. In reviewing the ANOPR studies, it was foreseen that the IRT might recommend more appropriate data sets or simulation models that could potentially improve or complement the analysis.

Thus, the role of the IRT was to assess the analytical processes used in the ANOPR studies and comment on:

- The reasonableness of assumptions that were made;
- The overall logic of the methodology;
- The quality of the data and data analysis/simulation tools that were used; and
- The validity of issues that have been raised with the analysis by stakeholder comments.

The IRT was to focus on issues that would likely change the results of the DOE analysis. However, short of re-doing the analysis, it was not possible to estimate the magnitude of differences in the results more than qualitatively.

The IRT stresses again that reasonable and competent professionals may differ on these issues. Alternatives to the TSD analyses could result in a *different* answer but not necessarily a *more correct* answer. The IRT has not attempted to impose on the ANOPR analysis how *the IRT would conduct the analysis*, but rather *whether the TSD used reasonable and defendable data and procedures* and, if not, *suggest alternative generally-accepted procedures and data that could be used*.

The next four sections each present an analysis of one of the four areas listed in Section 1.0. Due to the nature of the IRT's assessment approach (i.e., the team really consisted of six sub-teams) and the rapid response required (i.e., two months), the formats of these sections vary, and the analyses between sections may not be entirely consistent or cross-referenced.

Section 7.0 summarizes the results of Sections 3.0 through 6.0 and presents recommendations to DOE on modifications to the technical analyses making up the TSD.

3.0 REVIEW OF THE BUILDING ENERGY USE AND LOAD SHAPE CHARACTERIZATION ANALYSIS

3.1 Introduction

The purpose of DOE's building energy use and load shape characterization is to assess the energy and peak demand savings potential of different equipment efficiency levels across the range of buildings that use unitary systems. The building energy use and load shape data that result from energy simulations of a set of sample buildings is a major factor in determining electricity costs for cooling within the life cycle cost analysis.

In performing the building energy use and load shape characterization, DOE based its analysis on simulations run on a subset of buildings from the 1995 Commercial Buildings Energy Consumption Survey (CBECS) database that use unitary (or packaged) air-conditioning equipment. This subset of 1,033 buildings was selected from the overall CBECS database according to certain criteria, and complemented with further information as necessary to develop building profiles for the energy simulations.

Unitary A/C systems are used in differing manners in a broad range of building types in many different climates, and no single "perfect" set of building data exists to characterize their performance in the real world. In developing a building set and the associated energy performance profile that is intended to characterize unitary A/C performance on a national level, it is inevitable that the necessary application of engineering judgments and assumptions will have some bearing on the overall analysis results. Therefore DOE requested that the independent review team (IRT) address the following issues:

- Building Sample Approach
- Omission of Industrial/Manufacturing Buildings
- Electricity Prices for Multi-Building Facilities
- Distribution of Buildings in the 1,033 Sample
- Cooling Loads for Unitary A/C Systems that are not the Primary HVAC System

These issues were highlighted by DOE based on its interaction with stakeholders and its insights into the analysis. The IRT assessed these issues with the intention of determining if certain concerns are valid (meaning that this issue is a real one), and if DOE's analysis is reasonable in terms of its methodology, assumptions, and data sources. The intention was *not* to determine if DOE's characterization of commercial unitary A/C use in buildings was the "correct" method, because in an analysis of this scope and magnitude *no single correct method exists*.

Instead, this review focuses on the steps that were taken by DOE, whether they were reasonable, and if other "reasonable" approaches might have been adopted *that could change the overall results of the analysis*. This final point is critical, because an analysis of this scope must include many engineering judgments and assumptions, and one could suggest alternatives at every step of the analysis. What is most important, however, are those portions of the analysis that have bearing on the overall results (e.g., the economic and energy benefits associated with various efficiency levels), and whether these pieces of the analysis are sound. In cases where an issue

appears to be valid but its significance (i.e., its magnitude within the overall analysis) is hard to judge, the IRT offered suggestions on how to better determine the issue's significance.

The independent review was performed at a level where all relevant reference materials were thoroughly assessed in the context of the issues raised by DOE. Additional data sources were sought and used (if possible) to gain further insights into DOE's work. In some cases, no additional data on a particular issue existed in a useful format, and the review consisted primarily of assessing how DOE worked with whatever information *was* available. It is important to note that within the scope of this independent review, no additional simulations or modeling exercises were conducted. Therefore, the findings of this review are based solely on an evaluation of DOE's analysis complemented by other reference materials where possible. All of the resources used in conducting this review are listed in Section 3.8.

3.2 Building Sample Approach

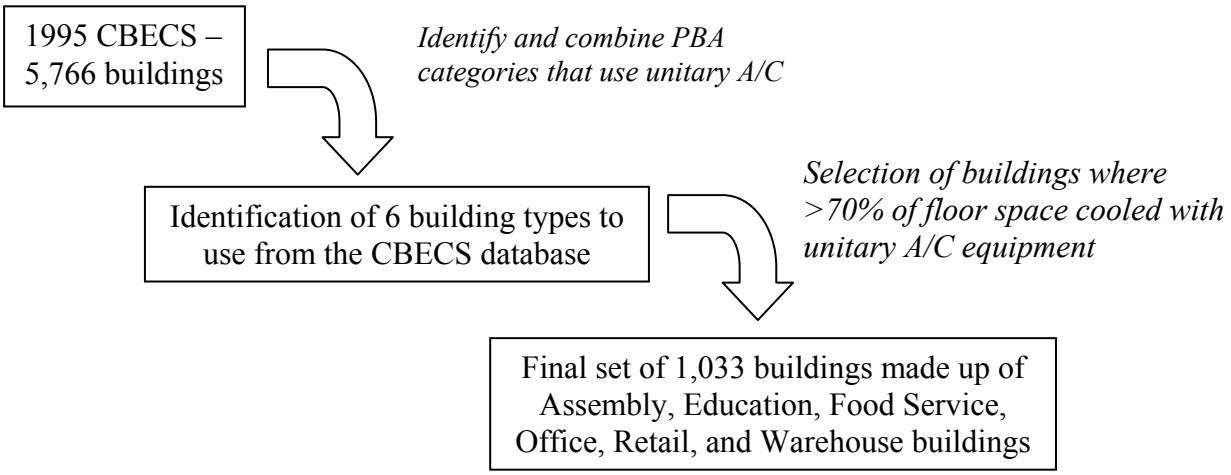
How well does the sample of buildings selected from CBECS represent the current operating conditions associated with the population of installed commercial unitary air conditioning equipment?

What other data sources might offer further insights into the distribution and use of commercial unitary air conditioning equipment?

What other methods might provide a better approach to selecting a representative set of buildings?

3.2.1 Introduction

In developing the sample of 1,033 buildings used to characterize the operation of unitary A/C systems, DOE started with the 1995 CBECS database and filtered it down to the 1,033 sample using criteria related to Principal Building Activity (PBA) and percentage of cooled space, as shown in the figure below[1].



[1] Chapter 6 of the ANOPR Technical Support Document gives more background information on the building sample development process.

As the figure illustrates, the analysis in support of the proposed rulemaking relies upon a subset of 1995 CBECS samples to characterize the distribution and operation of unitary A/C systems in commercial buildings. The development of this subset is an important factor in the overall analysis, because these are the buildings that ultimately portray where unitary systems are deployed and how they are operated.

Three aspects of this sample development process are assessed below:

- How effectively the building sample represents the population of unitary systems;
- What other data might offer information on the distribution of unitary systems; and
- What other methods might be used to develop a representative set of buildings.

One prominent issue related to the building set is the omission of industrial and manufacturing buildings, as well as commercial buildings on these types of sites, which use unitary A/C systems. Since this issue has been raised as an independent topic it will be discussed separately in the next section (Section 3.3).

3.2.2 Assessment

How well does the building sample represent the distribution and use of unitary A/C systems?

The Commercial Buildings Energy Consumption Survey (CBECS) is a representative national survey that collects energy-related building characteristics data and energy consumption and expenditures data for commercial buildings in the United States. CBECS offers a broad representative data source for the characteristics of commercial buildings in the US. The HVAC characteristics data contained in CBECS represent the best publicly available, national-level information on the distribution and use of unitary A/C equipment in commercial buildings. Further, each sample in the database is weighted to reflect how many similar buildings it represents in the actual population of commercial buildings.

Thus, by using the sample weights provided in CBECS, the 1,033 building sample can be assessed in terms of how thoroughly it captures those commercial buildings that use unitary cooling equipment. Based on DOE's analysis of the sample, the buildings in the sample represent 73% of the annual A/C energy use and 67% of the square footage of commercial buildings that cool at least part of their floor space with unitary A/C equipment. The IRT concludes that even after filtering out certain building types and buildings that cool less than 70% of the floor space with unitary equipment, these values indicate that the 1,033 sample effectively represent the distribution of unitary equipment in *commercial* buildings.

What other data sources might offer information on the distribution of unitary systems?

The assessment of this question required a review of available data products from DOE and the Energy Information Administration (EIA), the research community, industry groups, and private

entities. The most notable resources are discussed below, along with their data that are relevant to the rulemaking analysis.

1992 Commercial Buildings Energy Consumption Survey

In the 1995 CBECS (the data set used in support of the proposed rulemaking), EIA changed the way that the target population of "commercial buildings" was defined. Two types of buildings included in the 1992 CBECS, parking garages and *commercial buildings located on multi-building manufacturing facilities*, were excluded from CBECS starting in 1995.

The inclusion of commercial buildings situated on manufacturing sites in the 1992 CBECS is noteworthy because of the omission of *all* industrial/manufacturing buildings from the rulemaking analysis (see Section 3.3), including commercial buildings on manufacturing sites. The 1992 CBECS data offers some insights into the distribution and use of unitary A/C equipment in commercial buildings on industrial sites – information that is *not* included in 1995 CBECS or the rulemaking analysis. However, CBECS 1992 does not contain data on industrial or manufacturing buildings, just commercial buildings on these types of sites. This topic is discussed further in Section 3.3.

ARI Statistical Profile

The Air-Conditioning and Refrigeration Institute (ARI) is a major trade association in the HVAC industry and produces a Statistical Profile with data on HVAC equipment from manufacturers' perspective. The Statistical Profile includes information on cooling equipment shipments, efficiency levels, and trends over time. However, the data in the profile is highly aggregated and does not include information on the buildings where specific types of equipment are deployed.

BOMA Experience Exchange Report

The Building Owners and Managers Association's (BOMA) 2003 Experience Exchange Report contains operating income and expense data on over 3,000 public and private sector commercial properties throughout North America. Data is classified by categories such as building type, building class, building ownership, and hours of operation. The building expense data includes categories such as cleaning, repair and maintenance, and utility costs. The utility costs are disaggregated by energy source (e.g., electricity, fuel oil), but no further data is available beyond this level of detail. The only HVAC-related information included in this database is the HVAC subset under the Maintenance and Repairs category.

California Non-Residential New Construction (NRNC) Baseline Report

The California Non-Residential New Construction Baseline Report is a study conducted on behalf of the California Board for Energy Efficiency (CBEE). The study is based on surveys of the designers (architects and engineers) of new buildings in California, onsite audits, and DOE-2 building simulations. The onsite building audits are a collection of several sets of NRNC audits conducted during the 1990's, and represent nearly 800 sites. While much of this data is focused on commercial buildings – particularly office, retail, schools, and public assembly – some samples within the database fall into the "General Commercial & Industrial Work" and "Commercial & Industrial Storage" categories. The data for these buildings includes information on HVAC equipment type; this could be useful in assessing the distribution of unitary equipment across a range of building types at the state level. This information is publicly

available online in a database format. However, as a California data base, there is no accepted method to extrapolate it to the national level, either by itself or combined with CBECS. (That is, it would introduce bias to add NRNC to CBECS in order to "better" characterize buildings of certain types or climate zones.)

Manufacturing Energy Consumption Survey (MECS)
The MECS database, prepared by EIA, is a nationally representative sample of manufacturing establishments in the US. The most recent version of MECS in 1998 had a sample size of almost 18,000 plants and collected energy-related data across 36 industry groups and industries (based on the NAICS system). MECS data with relevance to this rulemaking analysis include total HVAC energy (not disaggregated by cooling or heating), number of buildings onsite (starting in 1998), and conditioned floor space (1994 MECS but not 1998).

Market Analysis and Information System (MAISY)
Market Analysis and Information System is a collection of databases (based in part on CBECS) developed from information on more than 800,000 individual utility customers throughout the US. MAISY contains energy data on both commercial and industrial customers, although the level of detail between these two groups varies. Load profile data for both types of buildings is contained in MAISY, and disaggregated hourly A/C loads are also provided for both types of customers. A/C equipment type is provided for commercial customers, but not industrial buildings. Industrial buildings in MAISY do, however, have sample weights that allow for the estimation of national-level data based on the samples.

Given these characteristics, MAISY contains sufficient data to perform aggregated load profile comparisons between commercial and industrial customers on a state basis or utility area basis. Based on a preliminary review, the IRT concluded that MAISY data could complement or guide the DOE analysis in some areas (Section 3.3) but could not replace CBECS data.

Many other data sets with smaller scale or less detailed data (e.g., utility-based studies), specialized data (e.g., only certain building types), or private (for sale) data are also available, but their level of detail and scope limits their usefulness to the rulemaking analysis. While a few of the data resources listed above might offer some complementary data that could help guide the rulemaking analysis, the use of 1995 CBECS as the primary data source for this analysis is reasonable. No national-level data sets detailing the distribution of unitary A/C equipment across all building types were found. The use of additional or complementary data in the analysis should also be viewed with some caution, because specially augmenting the analysis with auxiliary data would likely introduce bias.

What other methods might be used to develop a representative set of buildings?

The above discussions of available data and the level of representation provided by the 1,033 building set indicate that starting with the CBECS database and narrowing it down to the 1,033 sample was a sound method of developing a representative commercial building set. A few deviations from the method used are discussed below.

Consider including buildings where unitary systems conditioned < 70% of the floor area
By excluding those commercial buildings where unitary systems condition less than 70% of the floor area, the current analysis does not capture buildings where unitary systems are used in conjunction with other equipment or buildings that may be only partially cooled. While this exclusion might cause the analysis to miss some partial-load scenarios, it would be extremely difficult to predict the loads on unitary systems in these situations (see Section 3.6). The uncertainty introduced by assumptions and approximations needed to estimate these A/C loads would outweigh the appearance of increased "precision" from modeling additional buildings. This, coupled with the fact that the 1,033 building set already characterizes a major portion of commercial buildings with unitary systems, relegates this issue to a secondary consideration that would most likely not change the results of the analysis.

Consider using more up-to-date commercial building data from 1999 CBECS
The 1999 CBECS data set was not used for the building characterization analysis because the entire micro-data set was not available in time for this analysis, and this database excludes new buildings less than 10,000 square feet. Using the 1995 CBECS data helped to address these issues but may also skew the distribution of building vintage towards older buildings. This could potentially influence building characteristics, building loads, and the characterization of unitary A/C equipment.

A distinct advantage to using the 1999 CBECS data is the inclusion of some new buildings (those greater than 10,000 square feet). However, disadvantages to using 1999 CBECS include the minimum size requirement of new buildings and the fact that the 1999 survey revisited many of the 1995 samples, so the data would contain a great deal of overlap. Within the scope of this review, the IRT cannot estimate the magnitude of the difference in results from the 1999 CBECS. There is also no indication that the 1995 CBECS data are not representative of current commercial unitary A/C usage. These issues, plus the fact that roughly 60% of total sales in the HVAC equipment market are for replacement and retrofits[2] in existing buildings, likely reduce the significance of the building vintage issue that results from using 1995 CBECS.

3.2.3 Findings

The approach used to develop the 1,033 building set was reasonable and resulted in a sample representative of the population of unitary A/C equipment in commercial buildings. (This section did not discuss the omission of industrial buildings; that is covered in the next section.)

Specific findings include:

- Using CBECS as the primary data source and starting point for developing the building sample utilized the best available single source of national-level data on HVAC and energy characteristics of commercial buildings
- The 1,033 sample is effective in characterizing the population of unitary A/C systems operating in commercial buildings

[2] ARI Statistical Profile. Air-Conditioning and Refrigeration Institute, 2001.

- Potential alternatives to the commercial building sample development process may be considered, but appear unlikely to change the results of the analysis.

3.3 Omission of Industrial/Manufacturing Buildings

In developing the building sample for the building energy use and end-use load characterization analysis, only commercial buildings were used. Buildings in the industrial/manufacturing sector that use unitary A/C systems were not included in the characterization of building energy use and load profiles.

What is the significance of this omission in terms of overall unitary A/C energy use and end-use load shapes in the building characterization?

3.3.1 Introduction

The building set used in this rulemaking analysis to characterize unitary A/C energy performance in buildings was developed from the 1995 CBECS database. This database contains 5,766 building samples with data on building type, building characteristics, and HVAC characteristics, including A/C equipment type.

In the 1995 edition of CBECS, no industrial buildings were included. This omission includes both industrial/manufacturing facilities as well as commercial buildings that are situated on industrial sites.

The omission of these building types has two impacts on the rulemaking analysis. First, it is possible that some buildings that use significant amounts of unitary A/C cooling energy are not captured in the building set. Second, it is also possible that these same buildings' electricity prices may be different, affecting the energy analysis results. Taken together, these two issues could potentially affect the load characterization, energy cost estimates, and ultimately the life cycle cost analysis of unitary A/C systems.

3.3.2 Approach

In reviewing the significance of the industrial buildings issue, two criteria determine if this issue is significant in the context of the overall results of the analysis. First, do industrial and manufacturing buildings consume a significant proportion of the energy used by the unitary A/C systems covered in this rulemaking? Without satisfying this criteria, industrial unitary A/C energy use is a "small slice of the pie" and will have little bearing on the overall results of the analysis, regardless of issues related to load shapes and electricity prices for industrial buildings.

Second, do industrial/manufacturing customers that use unitary A/C systems pay significantly different electricity prices for their cooling energy compared to commercial customers? For the omission of industrial buildings to be significant, both these criteria must be satisfied *simultaneously*. That is, it must be determined that those manufacturing/industrial buildings with lower tariffs are also buildings that use significant energy for unitary A/C systems. Concluding

that *some* industrial buildings use unitary systems and *some* industrial buildings have lower tariffs is not sufficient to establish significance. A correlation of these factors in the same subset of industrial buildings is necessary.

3.3.3 Assessment

Do Industrial/Manufacturing Buildings use a significant quantity of unitary A/C energy relative to the commercial building stock?

Understanding this issue requires having at least an approximation of unitary A/C energy use in 1) commercial buildings, and 2) industrial/manufacturing buildings. One estimate of annual packaged A/C energy use in *commercial* buildings in the US, based on the 1995 CBECS database, is 46.1 billion kWh[3], although the interpretation and manipulation of CBECS data can lead to different estimates.

As part of this independent review, 1995 CBECS data was used to develop an approximate range of unitary A/C energy use in commercial buildings based on two separate analyses using CBECS data (Appendix to Section 3.0). The results of the two approaches are within the same range, and indicate that annual energy use of unitary A/C systems in commercial buildings is in the range of 39 billion kWh to 46 billion kWh.

Determining unitary A/C energy consumption in *industrial* buildings is more challenging due to limited data. The Frazell analysis cited above uses a combination of 1998 MECS[4] and 1995 CBECS data to estimate that industrial buildings use 17.2 billion kWh annually for packaged A/C systems. This value, coupled with Frazell's 46.1 billion kWh estimate for commercial buildings, would indicate that roughly one-quarter of all packaged A/C system energy consumption occurs in industrial/manufacturing buildings.

A major assumption used in arriving at the 17.2 billion kWh result is that the proportion of packaged A/C energy consumption to total HVAC energy consumption[5] is the same in the commercial and industrial building sectors. While the level of detail contained in the MECS data necessitates an assumption of this type (MECS does not contain disaggregated data on cooling energy or cooling system type), the resulting energy consumption figure must be viewed cautiously due to the scale of this assumption.

This assumption is extremely significant and somewhat counter-intuitive. Lower electricity tariffs tend to be offered to larger electricity users (see next assessment issue). A light industrial facility might have a similar proportion of its electricity consumed by unitary A/C as a commercial facility, but its electric rates will also be similar. A large industrial facility that might have lower electric rates is likely to use most of its electricity for industrial processes, with A/C energy consumption comprising a small portion of the overall load. Thus, those industrial buildings for which this assumption may be valid (light industrial facilities) are likely to pay

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[3] *A Preliminary Quantification. The Effects of Excluding Industrial/Manufacturing Sites from the DOE Rulemaking to Determine Efficiency Levels of Unitary Large Equipment.* Charles Frazell, PE. March 2003.
[4] Manufacturing Energy Consumption Survey (MECS). Energy Information Administration, 1998.
[5] Where total HVAC energy is defined as the sum of heating, ventilation, and air-conditioning energy

similar electric rates anyway, and for those industrial buildings with lower rates (larger, heavier industry), the assumption is probably not valid.

Other estimates of annual unitary A/C energy consumption place the *total* energy consumption of packaged rooftop units in the US at 76 billion kWh annually[6]. This estimate includes both commercial and industrial building unitary A/C energy, and appears to originate from an April 2000 DOE screening analysis[7] [8]. However, the analysis used to arrive at this result is not transparent within either source, so this estimate of total energy consumption must be used with caution.

As illustrated by the uncertainties associated with the figures above, representative national-level data on the HVAC characteristics of industrial buildings are scarce. Using a more qualitative approach to the issue of packaged A/C systems in industrial buildings, DOE adopts the position that the general size of industrial facilities would tend to preclude the widespread use of packaged systems in the 5 to 20 ton range. However, this claim is not supported adequately to conclude that industrial packaged A/C use is not significant. In fact, recent research in California concluded that there is little correlation between building size and system size, and that unit size is driven more by the size of the conditioned zone rather than building size[9]. And for those industrial buildings that do use unitary equipment, it is likely to be the equipment covered in this rulemaking since roughly 90% of all rooftop unit shipments fall into this range.[6]

While national-level data on the use and energy consumption of packaged A/C equipment in industrial/manufacturing buildings is lacking, some information is available for a subset of these buildings: commercial buildings on industrial/manufacturing sites.

In 1995 CBECS, the Energy Information Administration (EIA) changed the way that the target population of commercial buildings was defined for the CBECS. A few types of buildings included in previous surveys (1989 and 1992) were excluded. One of these was commercial buildings located on multi-building manufacturing facilities. This category of building is not included in the DOE rulemaking analysis and represents one of the two types of industrial / manufacturing buildings left out of the analysis. The other type is actual industrial/ manufacturing buildings.

While the 1995 CBECS database does not include commercial buildings on industrial/manufacturing sites, 1992 CBECS *does* include data for such buildings, that represent 119,000 commercial buildings that are part of multi-building industrial/manufacturing

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[6] *Bridging the Efficiency Gap: Commercial Packaged Rooftop Air Conditioners*. Shugars, J.; Coleman, P.; Payne, C.; and Van Wie McGrory, L.

[7] *Screening Analysis for EPACT-Covered Commercial HVAC and Water-Heating Equipment.* US Department of Energy, April 2000.

[8] Communication with Phil Coleman of Lawrence Berkeley National Laboratory in October 2003. Mr. Coleman is a co-author of *Bridging the Efficiency Gap: Commercial Packaged Rooftop Air Conditioners*.

[9] *Background Research Summary. Integrated Energy Systems Productivity and Building Science.* New Buildings Institute for the California Energy Commission Public Interest Energy Research (PIER) Program, 200l.

facilities[10]. A multi-building facility is defined as a group of two or more buildings on the same site owned or operated by the same entity.

A preliminary analysis of 1992 CBECS performed for this independent review indicated that the total number of samples of commercial buildings on industrial/manufacturing facilities is 235, with over 22 million square feet of floor space. Of these building samples, over 92% of them (by number) fall into the Principal Building Activity (PBA) categories of Warehouse (36%), Office (34%), Vacant (14%), and Mercantile/Services (9%). The average building size in this sub-sample is 95,000 square feet.

Of these buildings which had some form of air-conditioning, 39% of them used packaged A/C systems. About two-thirds of this subset of buildings used packaged A/C for 100% of the building's cooling.

Using the building sample weights provided in CBECS 1992 to develop a national-level estimate, over 35% of commercial buildings (by number) on industrial/manufacturing sites have no cooling of any kind. In 1995 CBECS about 26% of commercial buildings (by number) were not cooled[11]. According to 1994 MECS, roughly 32% of the enclosed floor space in industrial buildings was not conditioned (which means no controlled heating or cooling). In general, the two types of buildings left out of the rulemaking analysis appear more likely *not* to be cooled compared to commercial buildings. This trend does not support the assumption that the ratio of packaged A/C energy to total HVAC energy is the same in commercial and industrial buildings.

Using the sample weights within 1992 CBECS further, the estimated national A/C cooling energy for packaged systems in commercial buildings on industrial/manufacturing facilities is 4.3 trillion Btu, or 1.3 billion kWh. This estimate is much smaller than the values given above for commercial buildings. But the 1.3 billion kWh is just the estimated unitary cooling energy for the 2.1 billion square feet of commercial buildings on industrial/manufacturing sites, and does not include *any* unitary cooling energy for the 8.4 billion square feet of manufacturing floor space that is conditioned.[12]

The following conclusions can be drawn from this brief analysis of commercial buildings on industrial/manufacturing sites:

- Buildings within this category are somewhat likely to be cooled with packaged A/C equipment *if they are cooled.*
- The estimated packaged A/C energy use in this subset of industrial/manufacturing buildings is small compared to commercial buildings, but this estimate does not include manufacturing floor space that is air-conditioned.

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[10] CBECS 1992, Table A25 – Multibuilding, Number of Buildings and Floorspace, 1992. Energy Information Administration, 1992.

[11] CBECS 1995, Table 3 – Census Region, Number of Buildings and Floorspace, 1995. Energy Information Administration, 1995.

[12] MECS 1994, Table A7 – Enclosed Floorspace and Conditioned Floorspace. Energy Information Administration, 1994.

- A large portion of these buildings (35%) are not cooled by any mechanical equipment.

Using this data on commercial buildings on industrial/manufacturing sites, one could arrive at an estimate of overall industrial/manufacturing sector packaged A/C energy *if* adequate data existed on the distribution of unitary A/C equipment in industrial buildings. Unfortunately, national-level data of this type that could complement CBECS and MECS is not available. Limited data on cooling equipment and cooling energy profiles in industrial buildings is available (see Section 3.2), which presents the challenge of how to assess the significance of this issue with incomplete information.

Is the cost of electricity for industrial/manufacturing buildings significantly different compared to commercial buildings?

The rulemaking analysis utilizes both a tariff-based approach and an hourly cost approach to arrive at the electricity cost estimates for the 1,033 building sample. The tariff approach to estimating electricity costs was based on a sample of tariffs from 90 utilities that serve 48.5% of commercial and industrial customers nationally. In most cases, DOE assigned a building to a tariff based on the peak demand (as simulated) over the previous 12 months. This tariff was then combined with the energy load profile for the building to determine electricity costs for cooling as well as the marginal energy cost savings that resulted from efficiency improvements.

Stakeholders have expressed concern that industrial facilities with unitary A/C systems would operate on less expensive tariffs, and that the omission of these buildings skews the cooling costs higher. The result of skewing cooling costs higher is to make higher efficiency A/C systems more attractive in the analysis due to increased energy cost savings.

Under the tariff pricing scheme used in the analysis, industrial buildings with packaged systems would face lower electricity costs for cooling *if* 1) these facilities were assigned to less expensive tariffs simply by virtue of being an industrial/manufacturing site, or 2) the load profiles of these facilities were of a magnitude and shape such that the facility qualified for a more advantageous tariff.

In examining the first question, DOE found through research that utilities typically do not distinguish between commercial and industrial customers, *per se*, in their tariffs. Only occasionally did DOE find utilities that will offer different tariffs for different business types (e.g., industrial vs. commercial). In investigating a portion of these cases more closely, DOE found in all cases that although the tariffs had different names, the rates were in fact the same.[13]

The IRT reviewed a sample of the utility tariffs collected under the rulemaking analysis.[14] The findings confirm that tariffs typically are not determined by the type of customer but rather by the electric power demand and usage characteristics of a customer. This fact, coupled with the breadth of DOE's utility tariff sample, indicates that tariffs based solely on business type are not a significant factor and would likely not translate directly into lower prices for industrial buildings on a scale that would alter the results of the analysis.

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[13] ANOPR Technical Support Document, Section 8.2.3.1.2, "Tariff-based analysis"
[14] Archive of Utility Tariffs: http://eetd.lbl.gov/ea/ees/tariffs/index.php

The second question – whether industrial/manufacturing load profiles would qualify these facilities for less expensive utility tariffs that would reduce the marginal savings from increased efficiency levels – is more difficult to answer. The determination of which tariff a building is assigned in the DOE sample is driven by the facility's demand, with higher demand levels corresponding to tariffs with less expensive unit energy charges (cents/kWh).[15] Also, through its research DOE recognized that *higher load factors (flatter loads) are associated with lower marginal rates* (ANOPR Technical Support Document Section 8.2.3.1.2).

In commercial buildings, air-conditioning loads can be a major contributor to the overall electrical load. Many of the other loads (lights, computers, communications) and occupants in commercial buildings serve to add to a building's cooling load. Air-conditioning demand is therefore a major factor in overall building peak demand and helps to determine the tariff as well as demand charges ($/kW). Demand levels vary tremendously from site to site, and may be greater than or less than demand levels in industrial buildings on a site-by-site basis. Load factors in commercial buildings generally tend to be lower than those for industrial buildings due to differences in operations and usage schedules. A few samples of commercial building load factors provided in the ANOPR Technical Support Document (Technical Support Document Section 8.2.3.1.2) ranged from 33% for a warehouse to 54% for a restaurant. Other references such as the MAISY database contain load factors based on building type, such as a summer load factor range of 42% to 72% for Office buildings[16]. While generalized load factors are useful for qualitative comparisons of large sets of buildings (e.g., commercial vs. industrial), any quantitative analysis related to A/C energy, peak demand coincidence, and tariffs must be performed with actual site-specific load data.

In industrial buildings, load factors are generally higher due to the types of processes conducted and operating schedules.[17] For these same reasons, A/C loads in some industrial facilities are a very small contributor to overall building demand and may have little or no bearing on determination of the tariff or demand charges. The peak demand of an industrial facility may be driven exclusively by industrial operations. In the aluminum industry, for example, the total HVAC electrical energy (of which cooling is just one component) is just 1.5% of the total facility energy[18]. Further, the peak A/C load may or may not coincide with the peak load of the overall facility, meaning the peak demand savings from increased A/C efficiency levels would be treated differently than they are in commercial buildings. Other references show that the largest utility customers in some areas (which will tend to be industrial facilities) have average weekday load factors around 0.86, while much smaller facilities (which will include many commercial buildings) have a lower load factor of 0.70.[19] Again, average load factors of this type are useful for general comparisons only.

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[15] For a more complete explanation of tariff structures and the impact of demand and energy use on rates, see Section 8.2.3.1.2, "Tariff-based analysis" of the ANOPR Technical Support Document.
[16] MAISY Database. http://www.maisy.com/isight1.htm
[17] *Opportunities for Microprocessor and Fuel Cell/ Gas Hybrid Systems in Industrial Applications,* Arthur D. Little, January 2000.
[18] MECS 1998. Table N6.2 – End Uses of Fuel Consumption. Energy Information Administration, 1998.
[19] *Market Monitor 2000 – A Report by the Division of Energy Resources.* Commonwealth of Massachusetts, Office of Consumer Affairs and Business Regulation, February 2002.

These findings regarding load characteristics in industrial buildings, combined with DOE's conclusion about the relationship between load factors and marginal rates, indicate that some industrial buildings (particularly those with high demands and high load factors) would have lower marginal rates within the rulemaking analysis. This in turn would reduce the energy cost saving benefits of increased A/C efficiency levels. Once again, this is only relevant to the analysis if these same buildings use a significant amount of electricity for unitary A/C.

3.3.4 Findings

Unitary A/C Use in Industrial Buildings

Taking into account DOE's data sources and analysis, external analyses and references, and rough estimates performed under this review, it is extremely difficult to arrive at a defensible estimate, using publicly available data, of unitary A/C energy use in those industrial and manufacturing buildings omitted from the analysis. In the absence of such an estimate, it is also difficult to judge the *significance* of unitary A/C operations in industrial buildings within the overall results of the analysis.

Despite these constraints, the following factors *do* indicate that this issue is *valid*, even if its significance cannot be determined currently:

- An estimate of 1.3 billion kWh of unitary A/C energy in commercial buildings on industrial sites. This is a small fraction of the commercial range, but it does not include any cooling energy for industrial or manufacturing floor space. The *total* floor space of this type of building is just ¼ of the *conditioned* floor space within industrial buildings.
- 79 billion kWh of HVAC electrical energy use in manufacturing buildings, some of which is consumed by unitary A/C systems.
- Approximations of 17.2 billion kWh for industrial unitary A/C energy and 76 billion kWh of *total* packaged rooftop unit energy. While these estimates involve debatable assumptions (e.g., the proportion of A/C energy used in industrial facilities) and non-transparent analysis, respectively, even if they are both 30% too high it would still result in a meaningful portion of unitary A/C in industrial buildings.

It must be stressed that the analysis cited in the stakeholder comments (Frazell 2003) assumes the same proportion of HVAC electricity will be used for unitary A/C in commercial and in industrial locations. This is probably not valid for those buildings that are primarily heavy manufacturing and have a significantly lower tariff than commercial buildings. For those light industrial buildings with loads similar to commercial buildings (i.e., those industrial buildings where this assumption may be more valid), their tariffs are also similar and the commercial life cycle cost analysis will apply. Since the estimate of 17.2 billion kWh of industrial unitary A/C electricity use rests upon this assumption, it is probably overstated.

While DOE's steps in the current analysis are reasonable given the available data resources, this issue has enough potential that DOE (possibly in conjunction with stakeholders) should determine if additional data or analysis could be developed with reasonable effort that would add clarity to the significance of this issue. That is, what intermediate steps could be taken to get a better gauge of the significance of industrial unitary A/C energy use in facilities with lower tariffs?

One possibility is to approach this issue from the opposite direction by reviewing the rulemaking analysis to determine how much industrial unitary energy use *would* be significant. That is, what minimum amount of industrial unitary A/C energy consumption would be enough to change the results of the analysis? This threshold for significance could then be compared to the rough estimates (e.g., 17.2 billion kWh) to determine if this issue warrants further examination.

Different Electric Rates for Commercial and Industrial Buildings

DOE's work in developing cost estimates for commercial buildings using its tariff methodology appears to be thorough and reasonable. As for the potential cost differences between industrial and commercial buildings, a review of DOE's analysis, its tariff archive, and information on load profiles indicates that this issue is likely a valid one. That is, it is likely that some industrial buildings would pay lower marginal prices for electricity.

The *significance* of this issue (e.g., does it change the results of the analysis) rests on *how much lower* industrial rates might be and how the A/C energy load relates to the whole building load in specific industrial facilities that use unitary systems. This issue is similar to the industrial building energy use issue discussed above, in that a diagnostic analysis should be considered that would offer more insight on the significance of the issue. The data available at this point only indicates that the issue is valid.

One possibility would involve using load profile data for specific industrial facilities, using a data source such as MAISY (that contains disaggregated A/C data for industrial facilities with national-level weighting factors). This analysis could focus on facilities within industries that use significant amounts of HVAC energy (e.g., computers, electronics) to help assure that relevant industrial buildings are being assessed. The load profiles and energy use data from such buildings could be combined with DOE's tariff database to arrive at energy cost estimates, which would in turn be compared to the commercial facilities in the rulemaking that are in the same utility districts. This type of approach would not characterize unitary A/C operation in industrial buildings, but it would provide an indication of the significance of cost differences between industrial and commercial buildings.

3.4 Electricity Prices for Multi-Building Facilities

In the building sample that DOE developed from the CBECS database, 373 of the 1,033 buildings are associated with multi-building facilities. Would the average price of electricity paid by this 373 building sub-sample likely differ from the average price of electricity of the 1,033 sample?

How likely are buildings associated with multi-building facilities to be separately metered for electricity and how likely are they to be on a separate rate structure from the multi-building facility?

3.4.1 Introduction

The issue of metering practices for multi-building facilities is significant to the rulemaking analysis because if buildings in this situation are metered collectively with other buildings on site, then they may qualify for less expensive rates. Treating these buildings as single-metered, stand-alone units could potentially result in the overestimation of energy costs and marginal cost savings estimates for these buildings.

3.4.2 Assessment

The IRT contacted a sample of utilities and other personnel experienced with metering practices to determine how multi-building facilities are typically metered and billed.

While each of the groups contacted stated that there was no absolute rule for how multi-building facilities are handled, the general trend was to independently meter each building on a multi-building site and to assign rate structures based on each individual building. Several explanations for this approach were provided:

- Metering individual buildings allows facility and energy managers to benchmark building performance more effectively.
- Metering individual buildings simplifies the management of leased-out buildings on a multi-building facility.
- As a site evolves over time, new meters are added as new buildings are constructed, resulting in a collection of individually metered buildings.

A few limited examples were provided in which account managers at a utility would aggregate loads from multiple meters on a site into a single profile at the customer's request. However, in general it was reported that buildings were metered and billed as stand-alone entities and not combined in any way with other buildings on the site.

The experience of the IRT is that under electricity deregulation a growing number of national accounts (e.g., nation-wide franchises) and "load aggregators" are negotiating combined metering and favorable rates for multi-building sites and even for separate sites (that will purchase their electricity, and be metered and billed), as a group. Such agreements are still uncommon, and with the varied nature and rate of "deregulation initiatives" throughout the nation, there is no way to factor this into the analyses supporting the ANOPR.

3.4.3 Findings

It is unlikely that the average price of electricity paid by the sub-sample of buildings on multi-building sites would differ significantly from the average price for the 1,033 sample based on any issues related to metering multi-building facilities. Currently the general trend for multi-building sites is to meter buildings separately and to determine rate structures based on individual buildings.

3.5 Distribution of Buildings in the 1,033 Sample

To what extent does the distribution of buildings in the 1,033 building sample accurately represent the distribution of actual commercial buildings by regions and climate?

3.5.1 Introduction

The 1995 CBECS sample was drawn to be representative of the commercial building population in the U.S. DOE asked the IRT to assess how representative the sample of 1,033 buildings drawn from 1995 CBECS was in terms of its geographic- and climate-based distribution. This issue focuses solely on the 1,033 building data set and how well its distribution represents 1995 CBECS and the total (national) commercial building population.

Within the context of the rulemaking analysis, by reducing the size of the sample used by selecting out buildings relevant to the analysis of commercial A/C, the same degree of statistical significance is not maintained when extrapolating to the national population as for the original complete 1995 CBECS data base. It is beyond the scope of the IRT to verify the various statistical parameters of the 1,033-building database, the robustness of these parameters relative to the overall CBECS database, and the implications of sub-dividing the 1,033 building sample into smaller sub-groups that are used to draw national-level conclusions.

This question posed by DOE is a *qualitative,* not a *statistical*, one, and one can *qualitatively* examine the sample of buildings used to characterize the operation of unitary A/C systems to see if all regions and climate zones are represented on an equitable basis. In general, the 1,033 building sample should mimic the distribution of the commercial building population by region and climate if the variances of parameters from which the sample was drawn are similar for each region and/or climate zone subset.

3.5.2 Assessment

Table 6.2.6 in the ANOPR Technical Support Document (TSD Section 6.2.2) provides an indication of how representative the distribution of the set of 1,033 buildings is in terms of region (census division) and building type. With similar levels of variability of data, regions with a larger building population such as the Pacific census division (157,511 buildings) would likely be more heavily sampled in the 1,033 set, while lower population regions such as the West North Central division (33,398 buildings) would likely be represented by fewer samples. The table below presents a portion of Table 6.2.6 from the Technical Support Document.

Census Division	# of Samples from the 1,033 Building Set	All Commercial Buildings	Number of Actual Buildings per Sample Building
East North Central	145	102,455	707
East South Central	83	102,069	1230
Middle Atlantic	98	73,803	753
Mountain	51	39,883	782
New England	50	33,480	670
Pacific	210	157,511	750

South Atlantic	197	120,693	613
West North Central	55	33,398	607
West South Central	144	120,465	837

The ratio of actual buildings in a region to the number of samples included in the 1,033 set (column 4) is expected to be approximately in the same range across the nine different census divisions (recognizing however that population size and variance within each division will dictate the sample size for assuring statistical significance when extrapolated to the national population). The results shown in the table above indicate that with one exception, the sample of 1,033 buildings is similar to the distribution of the commercial building population by region. With the exception of the East South Central division, all of the regions are within about 30% of the average actual buildings to sample building ratio (772). While the East South Central region had a lower representation, this could potentially be due to the amount of variances of buildings within the region.

After reviewing the DOE TSD, the IRT feels the set of 1,033 is effective in representing the regional distribution of the building population. However, as noted in Section 3.5.1 above, a national sample such as CBECS is designed to give statistically valid results for the overall (i.e., U.S.) commercial building population. Statistical significance and un-biased results are not assured for analyses of individual regions (or climate zones.)

In terms of the sample's effectiveness in representing the distribution of actual commercial buildings by climate, the following table uses information from Table 6.2.28 in the ANOPR Technical Support Document (TSD Section 6.2.6) and Table 1 from 1995 CBECS Building Characteristics tables.

Climate Zone					
	1	**2**	**3**	**4**	**5**
# of Samples from the 1,033 Building Set	71	210	209	302	241
All Commercial Buildings	493,000	975,000	1,070,000	1,103,000	937,000
Number of Actual Buildings per Sample Building	6,900	4,600	5,100	3,700	3,900

Climate Zones are defined in terms of Cooling Degree Days (CDD) and Heating Degree Days (HDD) as shown below:

- Zone 1: <2000 CDD, >7000 HDD
- Zone 2: <2000 CDD, 5500-7000 HDD
- Zone 3: <2000 CDD, 4000-5499 HDD
- Zone 4: <2000 CDD, <4000 HDD
- Zone 5: >2000 CDD, <4000 HDD

The table indicates that buildings in Climate Zone 1 have a somewhat lower proportion of buildings in the sample than the region's proportion of commercial buildings in the Nation. (For this Climate Zone, which is the coldest zone, there is only 1 sample in the analysis set for every 6,900 actual buildings, while in Climate Zone 4 there is 1 sample for every 3,700 actual buildings.)

Despite this, the range of sample to actual building ratios is reasonable, especially when one considers that the CBECS building set has been simultaneously screened based on several other criteria to arrive at the 1,033 sample. Some of these screening criteria may have had the effect of sampling more heavily in Climate Zones where air-conditioning is most frequently used or where there is a larger variance in building types.

3.5.3 Findings

Based on the qualitative analyses above, the buildings in the 1,033 sample seem to adequately represent the regional and climate-based distribution of the commercial building population in the United States. For the purpose of drawing conclusions about the national commercial building population, however, one must be very cautious about subdividing the overall CBECS sample and performing micro-simulations or -analyses where the results are very different by building type within a region (or climate zone), and then extrapolating the results to draw conclusions of national significance. This problem is discussed in terms of the BLAST simulation model in Section 4.0.

3.6 Cooling Loads for Unitary A/C Systems that are not the Primary HVAC System

Is it reasonable to assume that cooling loads are similar whether a unitary system conditions the majority or a minority of floor space in a building?

3.6.1 Introduction

This issue is essentially asking: will the cooling and electrical energy loads seen by a 5-ton unitary A/C unit that conditions 10% of the floor space in large building be the same as the loads experienced by a 5-ton unitary system that cools an entire building of smaller size?

3.6.2 Assessment

Whether the two 5-ton systems in the example above experience the same cooling loads depends on a number of issues, including:

- How closely were both units matched with the cooling load of the space that they are intended to condition?

- How is the unitary system that conditions only a minor portion of the floor space integrated with the other HVAC systems on-site? How completely are the conditioned spaces separated?
- How do factors such as cooling set-point schedules, operation/activity schedules, humidity controls, economizer operations, ventilation requirements, and load diversity influence the operation of both systems?

When faced with these questions it becomes apparent that it is quite difficult to say with much certainty that the loads faced by these two systems would be similar. In considering the factors listed above, DOE decided to focus the analysis on those systems that condition a majority of floor space, incorporating realistic judgments and assumptions regarding their operations as necessary.

Those systems that condition a minority of the floor space would generally introduce more uncertainty in assumptions regarding their operational characteristics. Unitary systems that are deployed in buildings with other A/C systems may be operated in many ways, which makes it hard to accurately characterize their operations within the analysis.

It should also be noted that modeling only systems that condition 70% or more of a building's floor space resulted in a sample set that captured 73% of the annual A/C energy in commercial buildings that use unitary A/C systems. This fact, coupled with the increased uncertainties of characterizing equipment operation in buildings with a minority of floor space cooled by unitary equipment, justifies the decision to focus on buildings with 70% or more floor space cooled by unitary systems.

3.6.3 Findings

It is difficult to judge whether cooling loads would be similar in buildings with a majority versus a minority of floor space cooled by unitary equipment. Characterizing the operation of unitary systems in buildings where they condition a minority of the floor space would involve more uncertainty in assumptions and judgments. This uncertainty, combined with the fact that the "70% and over" building sample captures a large cross-section of buildings with unitary equipment, led the IRT to conclude that selecting only buildings with a majority of floor space conditioned by unitary systems was a reasonable decision.

3.7 Summary

In the independent review of issues related to the building sample used in the rulemaking analysis, these findings were made:

Building Sample Development and Representation

- The 1,033 building sample set developed from 1995 CBECS effectively represents the distribution of unitary equipment in commercial buildings.

- The use of 1995 CBECS as the primary data source for the building sample development is reasonable.

- No national-level data sets detailing the distribution of unitary A/C equipment across all building types (including industrial) were found.

- Some auxiliary data resources exist that could help guide the rulemaking analysis and offer insights into the significance of other issues highlighted in this review.

- Potential alternatives to the commercial building sample development process may be considered, but appear unlikely to change the results of the analysis.

<u>Omission of Industrial Buildings – Impact on Unitary A/C Energy Use</u>

- The claim that excluding industrial buildings from the analysis leaves a meaningful portion of unitary A/C energy out of the rulemaking analysis is *valid* – meaning that the claim is legitimate and this issue has some impact on the analysis. The available data on unitary A/C energy usage in industrial buildings indicates that these buildings use a meaningful amount of unitary system cooling energy. This merits further analysis. However, the quantity of industrial building unitary A/C energy is unlikely to be as large as estimated in the stakeholder comments.

- Downplaying the use of unitary cooling equipment in the industrial sector based on the general size of industrial buildings is not adequately supported in the rulemaking analysis and runs contrary to other recent building research.

- Estimates of unitary A/C energy in commercial buildings on industrial sites are small but not insignificant. These types of buildings, combined with actual industrial and manufacturing buildings, represent buildings that use unitary A/C equipment that were not included in the rulemaking analysis.

- Rough approximations of unitary A/C energy in industrial buildings indicate that packaged systems in these buildings consume a meaningful amount of energy, even if the estimates in the stakeholder comments are overstated to some extent.

- The lack of data on the distribution of unitary A/C equipment in industrial buildings prevents the determination of whether excluding this portion of A/C energy is *significant* (e.g., would it change the results of the analysis were it included?). Additional efforts to arrive at an estimate of how much industrial unitary energy use *would* be significant could help to clarify this issue.

<u>Omission of Industrial Buildings – Impact on Load Profile and Energy Costs</u>

- The claim that industrial and commercial buildings would pay different prices for energy based on the load characteristics of these two types of buildings is *valid*. This finding is

based on a review of the rulemaking analysis, the tariff archive, and general information on load profiles.

- The *significance* of this issue (would it change the results of the analysis) depends on how much lower industrial rates might be and how many industrial facilities that use unitary A/C equipment would pay lower rates. At this point the significance has not been determined, but additional analysis involving industrial energy and load data and the rulemaking tariff database could potentially help to clarify the issue.

- Tariffs based on business type (e.g., an "industrial" tariff) are not a significant factor and would likely not translate into lower prices for industrial buildings on a scale that would alter the results of the analysis.

Electricity Prices and Metering Practices for Multi-Building Facilities

- The general trend for multi-building sites is to meter buildings separately and to determine rate structures based on individual buildings.

- It is unlikely that the average price of electricity paid by the sub-sample of buildings on multi-building sites (373) would differ significantly from the average price for the 1,033 sample based on any issues related to metering multi-building facilities.

Distribution of the Building Sample by Region and Climate

- The distribution of buildings in the 1,033 sample adequately represents the regional- and climate-based distribution of the commercial building population.

- Within the context of the energy use simulations, caution must be exercised when taking the national CBECS sample, subdividing it, performing simulations, and extrapolating the results to draw national-level conclusions. (Addressed in Section 4.0 of this report)

Cooling Loads in Buildings where Unitary A/C Cools Only a Minor Portion of the Space

- Characterizing the operation of unitary systems in buildings where they condition a minority of the floor space would involve more far-reaching assumptions and judgments, compared to buildings where unitary systems cool all or most of the building.

- Including only those buildings that cool a majority of floor space with unitary systems in the building sample captures a broad cross-section of commercial buildings with unitary equipment and is a reasonable approach.

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Appendix to 3.0 Estimates of Unitary A/C Energy Use in Commercial Buildings

Approach #1

From 1995 CBECS Table 3 (in the Energy End Uses Section of CBECS)

	Column A Electrical Cooling Energy Consumption **in Buildings with This Type of Cooling Equipment*** **(trillion BTU)**	**Column B** Percentage of Total Reported Electrical Cooling Energy by Equipment Type	**Column C** Adjusted Electrical Cooling Energy by Equipment Type *** **(trillion BTU)**
Residential Type			
Central AC	65	12.4%	42.0
Heat Pumps	62	11.8%	40.1
Individual AC	66	12.5%	42.7
District Chilled Water	4	0.8%	2.6
Central Chiller	102	19.4%	65.9
Packaged AC Units	**205**	**39.0%**	**132.5**
Swamp Coolers	16	3.0%	10.3
Other	6	1.1%	3.9
Total	**526**		340.0
Total Electrical Cooling Energy in Commercial Buildings (trillion BTU)**	340		

* This is **NOT** the energy used by the given type of equipment. Instead, it is the electrical cooling energy used by buildings that contain this type of equipment.
The cooling energy for buildings with multiple types of cooling equipment will be counted in more than 1 category.

** From Table 3. Electricity Consumption by End Use, 1995.

*** The adjusted value calculates the cooling energy broken out by equipment type by proportionally adjusting the reported values in Column A to account for the "double-counted" cooling energy.
For example, since buildings with Central Chillers represent 19.4% of the total reported electrical cooling energy (Column B), the reported cooling energy for buildings with Central Chillers was adjusted downward by 19.4% of the "double-counted" energy = 526 - 340 = 186. So the Central Chiller cooling energy was adjusted from 102 - .194(186) = 65.9

132.5 trillion BTU (for packaged A/C) = 38.8 billion kWh in site electricity (3412 Btu/kWh)

Approach #2 — Using 1995 CBECS Table 2. Energy End-Use Intensities for Sum of Major Fuels

Cooling EUI for buildings with packaged A/C units = 7.9 kBTU/sq foot

Packaged A/C units are used in buildings with a total square footage of 26, 628 million square feet *(using this square footage offers a generous estimate of unitary energy use because these buildings are not cooled exclusively with unitary systems)*

An extreme upper limit for packaged A/C energy use is therefore

(7900 BTU/ sq ft) * (26, 628 million sq ft) = 210.36 trillion BTU
= 61.6 billion kWh

However, since packaged A/C systems do not cool all of the square footage in these buildings, it is more reasonable to use an estimate of how much floor space is actually conditioned by unitary systems. Using Table 3C - "Main Cooling Equipment, Cooled Floorspace" from *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Expenditures* (EIA),

the total cooled floor space in commercial buildings is:	36,001 million sq ft
According to this same report on p. 27, packaged A/C units cooled 55% of all cooled floorspace, or:	19,800 million sq ft
Using this area conditioned by unitary systems with the Cooling EUI of 7.9 kBTU/sq foot, the estimated energy use	**= 156.42 trillion BTU** **= 45.8 billion kWh**

4.0 EVALUATION OF THE BLAST ENGINEERING ANALYSIS

4.1 Introduction

The Department of Energy (DOE) is preparing an Advance Notice of Proposed Rulemaking (ANOPR) for minimum efficiency standards for unitary air conditioners. The ANOPR and supporting documentation will set minimum efficiency standards. This section summarizes a review of several aspects of the DOE analyses supporting the ANOPR, including:

(1) The rooftop air conditioning model used in BLAST

- BLAST's inability to model multiple compressor air conditioning units;
- The temperature at which head pressure controls are activated;
- Modeling the saturated condensing temperature;
- Modeling the saturated suction temperature;
- Validation of the BLAST model;
- Capacities of air conditioners simulated in the DOE analyses;
- Assumptions about the maximum efficiency of commercially-available unitary air conditioners; and
- Inability to model part load performance.

(2) Some of the primary assumptions used by DOE for the analyses to support the ANOPR

- Correcting citation of A/C efficiency levels in ASHRAE 90.1-1999;
- Assumptions on use of low-emissivity glass in commercial construction; and
- Assumptions about economizer use.

(3) A review of the use of CBECS data to characterize the commercial buildings and energy use for the analyses supporting the ANOPR

- Statistical significance of results obtained by simulating performance of buildings in small sub-samples of CBECS;
- Estimation of air conditioning energy use from CBECS data;
- Suggested method to resolve this issue; and
- Calibrating the BLAST model to individual buildings.

Each issue is discussed below:

4.2 Review of the Rooftop Model in BLAST

Rooftops are modeled in BLAST as single compressor direct expansion (DX) condensing units. The original DX model was published by Hittle in 1982. The equations described in the DX condensing unit HELP files of the BLAST computer program are essentially the same as those outlined in the model by Hittle (1982). There are minor differences in some of the constants and a normalization routine to estimate the full load power ratio.

The model in BLAST has some significant restrictions that directly affect the DOE analysis. In addition, the BLAST analysis used to support the ANOPR appears to have some assumptions that should be reevaluated.

4.2.1 The rooftop model in BLAST assumes a single compressor air conditioner with compressor unloading

A single compressor rooftop unit is a reasonable assumption for rooftop units with a capacity under 10 tons (120,000 Btu/h), but it is not a reasonable assumption for larger units. The ANOPR includes units with capacities up to 20 tons. Many of the units between 10 and 20 tons have multiple compressors. The BLAST rooftop model is not capable of modeling these types of rooftops. As currently configured, BLAST should not be used to model the larger capacity rooftops. With multiple compressors, the part load performance should be much better than would be for single speed, single compressor units. Thus, the actual energy use of the baseline and improved efficiency units will both be less than predicted by BLAST.

In Section 4.2 of the TSD, a multiple compressor rooftop unit is portrayed as an option that can improve the annual energy use, but have no effect on the nominal full load EER. Multiple compressor units are more the norm in the larger rooftop class. Thus, the baseline unit should have multiple compressors in it. The compressor model in BLAST has a simple routine that simulates cylinder unloading in single speed compressors. As was pointed out in comments by Lennox (2003), the BLAST part load model of cylinder unloading has EER trends as a function of temperature that are different than the performance of a multiple compressor rooftop. If BLAST cannot model a multiple compressor rooftop unit, then it should not be used to predict the energy use or savings of the larger class of rooftops.

We believe that this is a significant deficiency in the analysis and needs to be addressed. One way to address the deficiency in BLAST is to develop a multi-compressor rooftop model. This will take time to develop the model, validate it, and implement it in BLAST. Without a new model, BLAST will not capture the part load performance of multiple compressor rooftops found in the larger capacity class.

The part load model in BLAST assumes the compressor has cylinder unloading. Discussions with several manufacturers indicate that many of the smaller rooftop units use hermetic compressors, which do not have unloading capabilities. For these units, the compressor will cycle on and off as the cooling load decreases below the steady state capacity of the unit. We would expect the part load efficiency of a unit that cycles on and off to be less than one with cylinder unloading. If the part load on/off cycling performance could be characterized, it would be possible to define a set of coefficients that could be used in BLAST.

4.2.2 The temperature used for implementing head pressure controls is excessively high

Head pressure controls are used in commercial air conditioners to artificially keep the head pressure high when the outdoor temperature is low. This maintains a sufficient pressure across the expansion device to ensure proper refrigerant control in the system. The amount of pressure required across the expansion device will depend on whether it is a thermal expansion valve, fixed short-tube, or electronic expansion valve. For rooftops, head pressure controls are often

implemented by either varying the speed of the condenser fan or cycling the condenser fan(s) on and off.

In BLAST, head pressure controls are implemented by specifying the minimum saturated condensing temperature (MSCT). This is the minimum refrigerant temperature that the condenser will operate at during the simulation. Normally, as the outdoor temperature drops, the condensing temperature will also drop in an air conditioning system. The default value for the MSCT in BLAST is 100 ºF(37.8 ºC). BLAST calculates a saturation temperature in the condenser based on the outdoor temperature and heat transfer characteristics of the condenser. We would expect 100ºF to correspond to an outdoor temperature of about 75ºF. If the calculated saturation temperature is less than 100 ºF, then BLAST will automatically keep the refrigerant condensing temperature at 100 ºF. This value for MSCT is high. A review of some literature from manufacturers as well as some discussions with their engineers indicated that current rooftop units are designed to operate down to at least 45 ºF outdoor temperature without head pressure controls. At this outdoor temperature, the condensing temperature would correspond to nominally 65 to 70 ºF, depending on the design of the condenser. Thus, the MSCT for these units would be 65 to 70ºF, not 100ºF. The impact of using the default value (100ºF) for MSCT versus a more reasonable 65 to 70ºF is that the energy use calculated in BLAST will be unrealistically high. The actual percentage increase in energy use will depend on the cooling load and number of hours that the outdoor temperatures are between 45 and 75ºF. There may be some parts of the country (South Florida or South Texas) where units would not even need head pressure controls or they would be used sparingly because temperatures rarely get below 40ºF.

The sample BLAST deck shows that the default MSCT was used because it never was reset. The default value should not be used. We strongly recommend that the analysts contact the major rooftop manufacturers to determine: (1) a reasonable range of outdoor temperatures that their units operate before needing head pressure controls, and (2) how head pressure controls are implemented in the units (i.e., actual saturation temperatures, whether fan cycling, etc.). While we have provided suggested values here, we feel reasonable values of MSCT should be developed and fully documented.

4.2.3 <u>The analysis supporting the ANOPR did not factor in all the capacity-related variables in BLAST</u>

In the BLAST rooftop model, the saturated condensing temperature (SCT) is calculated using the equation:

$$\mathrm{SCT} = OADB + \frac{(\mathrm{LOAD}(1+\mathrm{DFLPR}))}{\mathrm{CUA}} \qquad (1)$$

where,

OADB = outside air dry bulb temperature
LOAD = total load on the condensing unit
DFLPR = design full-load power ratio
CUA = condenser U-factor

The default value of CUA is 27.43 kBtu/(hr ºF). The documentation in the help files clearly shows that this CUA is for a unit with a cooling capacity of approximately 500,000 Btu/hr (40+

tons). The description in the Hittle (1982) paper makes it clear that CUA varies with the capacity of the unit. Both the BLAST documentation and Hittle (1982) show how this value can be estimated from manufacturer's data. The impact of using the default value is an underestimate of the condensing temperature for all units with capacities less than 40 tons. The impact on the analysis is twofold. First, an underestimate of the SCT will decrease the estimate of the energy use of the rooftop unit. The power of the unit is dependent on the difference between the saturated condensing temperature and the saturated suction temperature (SST). An underestimate of the SCT will produce a smaller (SCT – SST), which will *decrease* the estimated power consumption of the unit. The second impact is that an estimate of a smaller SCT will force BLAST to implement head pressure controls at a higher outdoor temperature than it would with a reasonable value of SCT. For example, assume a 5 ton (60,000 Btu/hr) rooftop unit is being modeled and the outdoor temperature is 95ºF. Using Equation 1, BLAST would calculate SCT as:

$$\mathrm{SCT} = 95°\mathrm{F} + \frac{\left(60000\frac{\mathrm{Btu}}{\mathrm{hr}}(1+0.326)\right)}{27.43\frac{\mathrm{kBtu}}{\mathrm{hr°F}}} = 95°\mathrm{F} + 2.9°\mathrm{F} = 97.9°\mathrm{F} \qquad (2)$$

In reality, the CUA for a 5 ton unit should be about 3.31 kBtu/(hºF). A more realistic calculated value of SCT would be:

$$\mathrm{SCT} = 95°\mathrm{F} + \frac{\left(60000\frac{\mathrm{Btu}}{\mathrm{hr}}(1+0.326)\right)}{3.31\frac{\mathrm{kBtu}}{\mathrm{hr°F}}} = 95°\mathrm{F} + 24°\mathrm{F} = 119°\mathrm{F} \qquad (3)$$

BLAST relies on the SCT calculation and MSCT to determine when head pressure controls should be engaged. Using the default value of CUA along with the default value of MSCT (100ºF) would mean that the head pressure controls would already be in use when the outdoor temperature is 95ºF! In reality, this would not happen because the head pressure controls would not engage because the actual SCT would really be about 120ºF, not 97.9ºF.

Using the default CUA is a major error in the BLAST analysis used to support the ANOPR. Given that the largest rooftop unit covered by the ANOPR is 20 tons, every one of the units simulated will have an estimated SCT that is too small. We believe all BLAST runs used to support the analysis of the ANOPR will need to be rerun with more reasonable values for the CUA for each rooftop used in the buildings. Given that some of the buildings modeled have 15 or more rooftops, individual CUAs consistent with the capacity of the units must be estimated and input for each unit. Hittle (1982) and the BLAST HELP files provide illustrations of how this can be done using manufacturers' published performance data. CUA data for each of the rooftop units used in a building must be estimated and input into BLAST for the baseline rooftop units. We would also expect the CUAs to vary between the lower efficiency baseline units and the higher efficiency units. High efficiency units might have larger condensers, high performance fins, etc. that would provide a larger CUA than a lower efficiency unit. Thus, CUAs also need to also be developed for each of the higher efficiency units analyzed.

4.2.4 The rooftop model assumes a low saturated suction temperature

The user can input the "Design Saturated Suction Temperature" (DSST) or use the default value. The input file provided to the IRT used the default value of the DSST, which is 40ºF. BLAST calculates the estimated Saturation Suction Temperature, SST, based on the DSST, the amount of loading on the evaporator (CPLR), and the unloader throttling range (UTR). The default value of the UTR is 4ºF. Using the default DSST, with the default CPLR and UTR produces a SST with a minimum of 36ºF and a maximum of 40ºF. The IRT has previously measured SSTs for smaller (3 to 10 tons) package units in the Texas A&M University (TAMU) laboratory and have found that the SSTs for these units varied from 40 to 45ºF when the entering air temperature across the evaporator was 80ºF and outdoor temperature was 95°F. This would indicate that the DSST should potentially be adjusted up about 5°F.

In BLAST, the saturated condensing temperature (SCT) and the SST are ultimately used to estimate the power used by the compressor. The larger the difference between the SCT and SST, the larger the amount of energy used. Thus, if the SST is smaller than it should be, it would contribute to a larger difference between the SCT and SST, which would *increase* the estimated energy use. Correcting this problem is relatively simple in that the default value for the SST should not be used. Manufacturers should have sample data of saturated suction temperature from data they collect during testing of their rooftop units. These data could provide more realistic values for input into BLAST.

4.2.5 The rooftop model in BLAST has never been experimentally verified

The rooftop model implemented in BLAST dates back to a model developed by Hittle (1982). One of the recommendations in that paper was that the model needed to be experimentally verified. From a follow-up phone conversation with Hittle (2003), it was learned that the rooftop model has never been experimentally verified. While a similar chiller model (1983) developed by CERL went through a limited validation, the rooftop model never was. We believe using an engineering model that has not been verified with test data opens DOE to significant criticism. Engineers build models of processes and equipment, but rely on test data to make corrections in the model and to ensure the model is predicting the correct trends/values. Test data will also provide some assurance of the accuracy of the model. For residential sized air conditioners, the analyst has the option of using two well known and verified models from either Oak Ridge National Laboratories (ORNL) or the National Institute for Standards and Technology (NIST) (Rice 1991 and Domanski and Didion 1983). Both models have been used and compared against experimental test data. Without any experimental verification of the rooftop model in BLAST, it will be difficult for the analysts (and DOE) to say that their estimates of performance are ± 1% or ±20%. Besides the deficiencies already pointed out in the model, we think it is important DOE verify the accuracy of the rooftop model with experimental test data. Because there are two classes of rooftop units, at a minimum verification should be done for a unit in each of the size classes. Failure to provide at least some minimum verification of the rooftop model with test data will lead to doubt of the validity of the BLAST analysis as well as all the economic analysis that depends on it.

This is not to say that the BLAST program is not valid. That BLAST has been widely used for over 20 years illustrates that its simulations appear reasonable, and its results are used and accepted for HVAC studies. However, the standard of analysis for a building owner who wishes

to evaluate various A/C models, an engineering team trying to estimate the value of improved A/C efficiency, or an Energy Services Company performing an audit to determine which efficiency measures to implement is not nearly as rigorous as the standards DOE must meet to justify regulations of the importance and breadth of the proposed NOPR. The IRT does not feel BLAST is invalid; we are concerned that without experimental validation of the rooftop model, it might be difficult to defend the analysis in a public hearing.

4.2.6 The BLAST analysis includes rooftop air conditioners outside the range of capacities of the two classes being analyzed

After reviewing the example BLAST input files for two different buildings, the files indicate that a separate packaged rooftop unit was used for each thermal zone in the building regardless of the zone size. This approach does not match the real world implementation of packaged rooftop cooling systems. A proper application of the model would have used a single rooftop to serve the loads for several smaller zones. If the point of the BLAST simulation is to evaluate units in the five to twenty ton capacity ranges, then the total loads handled by the units should be in that range of capacities. Table 4-1 below shows the packaged units used in one of the simulations. The capacity of the units ranged in size from 2.3 to 17 tons. Only three of the rooftops are actually covered by the proposed standard for the two classes of rooftops. All of the other 12 zones are handled by residential-sized equipment. Either the equipment needs to be modeled differently or the buildings should be rezoned so that appropriately sized rooftops can be used to cool the building.

Table 4-1 – Capacity of the air conditioners used in the 15 zones in one of the BLAST input files

Zone	Tons
1	2.8
2	3.3
3	2.3
4	3.0
5	16.3
6	3.7
7	4.4
8	3.0
9	4.1
10	16.4
11	3.8
12	4.5
13	3.1
14	4.0
15	17.0

4.2.7 The maximum efficiency of the rooftops used in the analysis is too low

Section 3.5.1 of the TSD provides a description of the efficiency levels of the rooftop classes. The maximum technologically feasible design that DOE chose to consider was one with an Energy Efficiency Ratio (EER) of 12.0. The Consortium for Energy Efficiency (CEE 2003) publishes summary tables of Air Conditioning and Refrigeration Institute (ARI) data for rooftops by manufacturer. The data include capacity, IPLV and EER on current units on the market.

These data indicate that for the 75 to 135 kBtu/h capacities, there are 4 units with EERs *over* 12.0. In fact, the highest is 13.5. For the capacity range from 135 to 240 kBtu/h, there were six units with an EER of 12.0 or above. The DOE Unitary Air-conditioner Program (UAP), under its Unitary Air Conditioner Technology Procurement, lists an 88,000 Btu/h rooftop model with an EER of 13.5 (price $4,325) and a 115,000 Btu/h model with an EER of 13.4 (price $5,525). There are units that can be purchased today with efficiencies as much as 12% higher than 12.0. This is similar to the residential air conditioner/heat pump analysis in the early 1980s. At that time, DOE published that the maximum technologically feasible SEER for residential air conditioners was 10.4 when there was an air conditioner with a SEER of 14.0 on the market (O'Neal, 1985). The DOE should closely re-examine the issue of what the maximum technologically feasible efficiency EER should be before publishing the ANOPR.

4.2.8 Ignoring part load performance excludes many options that could improve energy use

In Section 4.2 of the TSD, a statement was made that "there are technologies available in the marketplace which typically have no impact on the EER (nominal full-load) rating, but which may improve annual energy performance." A list is then provided of technologies that DOE would not consider. The issue of multiple compressors was discussed earlier. Given that rooftop units are typically much more complicated than residential units and must, in many cases, operate at part load conditions for a large fraction of the year, it seems inconsistent for the DOE to incorporate part load performance in residential air conditioner standards and ignore it for commercial air conditioner standards. Residential equipment performance is based on the Seasonal Energy Efficiency Ratio (SEER). The commercial equipment equivalent to SEER is the Integrated Part Load Value (IPLV). Residential units with multiple speed compressors, fans, variable speed compressors, all can be tested, performance quantified, and assigned an SEER. To ignore the many options available to rooftop manufacturers to improve part load performance and annual energy usage while having to justify the minimum standards on the basis of calculated annual energy use and dollar savings is inconsistent. Units with similar EERs can have dramatically different IPLVs. For example, in a recent report by TIAX (2003), they designed and tested three nominal 10 ton rooftop units that had EERs of between 9.3 and 10.8, but which had IPLVs that ranged from 12.8 to 14.1. These IPLVs are about 20 to 30% higher than similarly sized units on sold on the market in 2003 with similar EERs (CEE 2003). The units with the higher IPLV would use significantly less energy than those with lower IPLVs but have the same EER. The TIAX report illustrates that EER alone should not be used as the performance criteria for rooftop units. The IPLV is in the existing test procedure and can easily be reported by the manufacturer. BLAST is currently incapable of handling most of the options listed in Section 4.2 of the TSD. Thus, a new model would need to be developed that could include these options. Differentiating IPLV from EER also requires more sophisticated consideration of electric energy and demand pricing. (While the IRT feels that A/C efficiency standards for this class of equipment are better based on IPLV than EER, *DOE is required by statute to base this rulemaking on EER*.)

4.2.9 Summary

BLAST includes a rooftop air conditioner model that can be combined with the building models in BLAST to estimate the annual energy use for cooling of rooftop air conditioners. The analysis

used to support the ANOPR used BLAST. There were a number of limitations of the analysis that were discussed. Some of these, such as specification of the condenser U-factor (CUA), the value of the design saturated suction temperature (DSST), the maximum saturated condensing temperature (MSCT), the maximum technological efficiency, and the use of rooftops outside the size range of the two capacity classes, can readily be corrected for future analysis with BLAST. However, there were several items that we believe make BLAST a poor choice for the engineering analysis tool to support the ANOPR. The biggest restriction in BLAST is that it only handles single compressor rooftop systems and models them with cylinder unloading. While the rooftops in the smaller class typically use single compressors, they are hermetic compressors and will usually use on/off cycling to control capacity. The IRT expects the part load performance of hermetic compressor systems to be different than that modeled with BLAST. Because many rooftops in the larger capacity class have two compressors, the part load rooftop model in BLAST will not provide a good representation of the larger capacity rooftops.

The IRT recommends that the verification of the rooftop model is important to provide confidence in the engineering analysis. The BLAST analysis provides the energy use and cost estimates that will be used to justify the setting of the minimum standards. Thus, it is important to have a model that has been verified.

4.3 Rooftop Efficiency and Controls

In this section, basic assumptions and data regarding rooftop efficiency and controls are discussed.

4.3.1 Efficiency Levels in ASHRAE Standards

In Figure 5.5.1 of the DOE TSD analysis, EER levels listed for the 7.5 and 15 ton units are labeled as ASHRAE 90.1-1999. While these levels were published as part of ASHRAE 90.1-1999, they are scheduled to go into effect two years after the 1999 Standard is published, i.e., in 2001. Therefore, the label in Figure 5.5.1 should read "2001 EER levels in ASHRAE 90.1-1999" not "ASHRAE 90.1-1999". Similar corrections may be needed for references to Table 6.2.8 EER Levels Selected for Building Simulations for Efficiency Cases 3 and 5. It is straightforward to correct these labels.

4.3.2 Window Characteristics

This section describes the use of low-emissivity (low-e) glazing in commercial construction. DOE assumed a linear growth of the application of low-e glass from 1.2% in 1985 to a 12.9% level in 1995, and on to an assumed current level of 20% market share. Even the linear growth leading to 20% is likely optimistic. From the IRT's experience, unless required by building codes, only very knowledgeable owners would have low-e glass installed in their newly constructed commercial buildings. Until the late 1990's, the premium for the upgrade from standard to low-e glazing was several dollars/ft^2 of glass area. Beginning in the early 2000's, many states began to adopt the International Code Council's (ICC) family of building codes. In those states that adopted the entire code set, it would also include the International Energy Conservation Code (IECC). Depending on HDD or CDD climate data, the IECC could require

the use of low-e glass. The ICC has no such provision for commercial construction. So, it is restated that even this modest application percentage for low-e application in commercial construction is optimistic.

In addition, the DOE assumed that low-e glazing was not used in their analysis for climate zones with < 4000 HDD and > 2000 CDD. This would eliminate the entire Southeastern portion of the United States, which includes Florida and Texas. These two states represent a considerable portion of the air-conditioning market in the U.S. Assuming low-e for heating only in the northern U.S. would underestimate the impact of high efficiency electric cooling equipment (lower load in building). Conversely, assuming use of low-e in southern climates as well would reduce the apparent cooling load on the HVAC equipment and allow for more efficient operation. In either case, any use of low-e glazing is generally on construction involving only very well informed owners.

4.3.3 Economizer Use and Control Assumptions

DOE states that they "originally were going to use fixed, dry-bulb economizers" for the analysis. They decided not to use that control strategy because of "problems" with BLAST'S simulation of that type of control when applied to "certain systems". While it is true that differential enthalpy control is available for economizer control, *our experience is that* it is *very seldom* chosen as an option on most smaller (7.5 – 15 ton) packaged equipment. It is usually the most sophisticated control strategy available and is also the most expensive control option. This range (7.5 – 15 ton) represents a very common application for small commercial construction and is the preferred choice for economic reasons. It is "cheap," low first-cost equipment. The savings are mostly in the labor required to complete an installation. It is significantly easier to install this type of equipment than a comparable capacity central system. As such, this range of equipment is usually specified (by the owner or engineer) to be a pretty basic package with a minimum of expensive add-on options.

A second issue has to do with whether economizers should be applied in all buildings. For example, in hot and humid climates, the applicability of an economizer operation is limited at best. The ASHRAE 90.1-1999 essentially eliminates the requirement for economizer in any area of the southeastern United States. Table 6.3.1 Minimum System Size for Which an Economizer is Required (ASHRAE 90.1-1999) has several entries for "N.R." that stands for "No Requirement". According to the weather data listed in Normative Appendix D, Table D-1, U.S. Climatic Data, there is not a single location in the state of Florida that would be required to have an economizer installed on any size HVAC system. DOE's assumption of economizer use is probably overstated and would lead to an overstatement of the opportunity for "free" cooling through the use of an economizer.

4.3.4 Summary

This section summarized some of the assumptions used in the BLAST analysis. These related to the window characteristics and economizer use and control. The IRT recommends that the DOE take a closer look at these items and the assumptions used in the analysis. Whatever assumptions are eventually used should have adequate justification to ensure they do not inadvertently bias the energy use calculations.

4.4 Comparison of BLAST Simulation Methodology and CBECS Estimates of Energy Use

In this section, the BLAST energy simulation methodology is discussed along with the CBECS estimates of energy use. An alternative methodology for estimating energy use from the CBECS data base is also discussed.

Previous analysis related to unitary air conditioners used "typical" building prototypes in energy use modeling analysis. The greatest level of detail in this analysis included seven building types and eleven climate zones (Chapter 6 of the DOE Documentation). While this analysis approach is attractive in its simplicity and certainly serves a purpose in the early stages of the kind of national modeling to which it was applied, its results suffer from a well known deficiency called aggregation bias

Aggregation bias shows up, for instance, when analysis of a "typical" office building yields results that are different than results based on analysis of a representative sample of small, medium and large buildings. These differences exist even when the average characteristics of all of the buildings corresponds to characteristics of the typical building. This type of error frequently occurred, for example, in analyses of demand side management programs that attempted to decrease diversified A/C load by cycling air conditioners. Modeling an "average" building would provide an "optimal" cycling strategy for the "average" system, but the effects of the DSM program on over- and under-sized units were very different, and did not "average" out to the effects of the typical or medium-sized unit. As a result, the implementation of a program designed with this aggregation error analysis was less load reduction and a greater drop-out rate than expected.

Aggregation bias can be minimized by increasing the number of "typical building types" and climate zones. The application of BLAST analysis to individual CBECS buildings reflects an attractive methodological framework for improving on previous analysis approaches. This use of a large number of individual buildings as the basis for analysis is often referred to as micro-simulation. Micro-simulation provides analysis of individual buildings whose results can be aggregated back to the population using weights that reflect the representation of each building within the population. However, increasing the number of building types within the limited CBES data sample will introduce bias error, as described in Section 4.4.1.

Application of the micro-simulation approach can substantially improve the accuracy of results and provide much greater detail concerning individual issues related to the analysis. Unfortunately, the analysis used to support the ANOPR is seriously flawed in a number of aspects, seriously calling into question the accuracy of energy use, customer cost and most other aspects of the analysis. These deficiencies are described in the following four sections. Modifications of the analysis required to rectify the deficiencies are also provided.

4.4.1 <u>CBECS Sample Building Issues</u>

The 1995 CBECS database was used as a basis for developing a sample of actual buildings using Unitary Air Conditioning Equipment. The CBECS survey is a well-designed and reliable source of information on US commercial utility customers. As with all surveys, the statistical precision

targets of the survey are achieved only for variables that were used in designing the sample. That is, CBECS has been designed to provide national and regional estimates of commercial sector buildings and energy use. Once one drills down to find more specific information, the precision of associated estimates declines because the sample of these customer types is much smaller than the sample of all buildings for which the survey was designed. For example, the 95% confidence interval around total US commercial floor space is +/- 3.4% (sample of 5765 buildings). Drilling down to determine floor space for food service buildings, one finds a 95% confidence interval of +/- 12.2 % (sample of 141 buildings). The food service floor space served by packaged air conditioning has a 95% confidence interval of +/- 17.08% (sample of 67 buildings).

There are an even larger number of "GeoClimate" regions formed from the intersection of census division and climate zones as indicated in Table 6.2.28 of the TSD. The 25 cells with CBECS buildings vary from 164 buildings in the largest to 5 in the smallest. 10 of the 25 cells have fewer than 20 sample buildings. To see the potential problem in attempting to distinguish among energy use characteristics (including load shapes) with this sample, consider the following. The East South Central census division includes three climate zones, 3, 4 and 5 with 14, 53 and 16 sample buildings, respectively. If a sufficient number of each of the 6 building types exists in each of the climate zones, no problem exists; however, the size of samples are too small to permit this situation. Since the CBECS sample was not designed to answer the relevant question in this analysis (i.e., building and energy use characteristics for the 6 building types and 25 GeoClimate zones) there is no assurance that, with these small samples, the collection of buildings will provide an acceptably accurate characterization of energy use for each of the 6 x 25 = 150 segments. For instance, given these small samples, there might be 0 restaurants in climate zone 3, 2 restaurants in climate zone 4 and 3 restaurants in climate zone 5 providing a bias towards climate characteristics of zone 5.

Given the importance of the sample characteristics with respect to accuracy of all of the policy results, the analysts should have addressed these issues carefully in their analysis and documentation.

DOE does recognize this problem indirectly in its economic analysis by assigning each building in the simulation sample to a subdivision, and then applying each building in the subdivision to each utility in that subdivision to increase the sample size.

Essentially, the analysis reuses individual building records for different utilities, presumably running the BLAST analysis in each utility location for each building. While some of the elements of this process are reasonable, the effort described above which applies all of the sample buildings in a geographic region to each geographic subset of the region (i.e., the utility service area) without re-weighting the building records creates a misrepresentation of the required micro-simulation sampling process, and one cannot determine the impact of these errors on the accuracy of the of the analysis results.

The most serious deficiencies in the analysis process can be rectified with the following efforts: (1) Calculate the statistical accuracy of the total sample, treating it as a stratified sample. If necessary, merge the 1992 CBECS data with the 1995 CBECS data. This would more than double the sample of buildings, significantly improving the statistical reliability of the results and (2) While "reusing" individual building records for different regions and utility service areas to

expand the sample representation is desirable (after rerunning the BLAST model with the appropriate weather data), these building records must have new weights developed in a post-stratification process based on counts of establishments by employee size in the states and utility service areas.

4.4.2 CBECS End Use Energy Use Information

One issue that has arisen in the evaluation of the BLAST-predicted cooling estimates is the discrepancy in the BLAST and CBECS air conditioning energy use intensities (EUI's). Chapter 6, Section 6.3.1 of the analysis documentation provides a comparison of BLAST and CBECS air conditioning EUI's. The report states that "*The CBECS EUIs were derived from the reported total annual electric cooling energy*," which seems to suggest that the CBECS air conditioning EUI's for each CBECS record are metered data. However, end use EUI's for each of the CBECS building records are estimated in a calibration process which applies the Facility Energy Decision Screening (FEDS) system to model each individual record's space heating, cooling, ventilation, lighting, and water heating energy use with detailed building engineering simulations A summary of this process is provided at http://www.eia.doe.gov/emeu/cbecs/tech_end_use.html The calibration process used monthly billing data which is available for most CBECS billing records to calibrate the FEDS model and to adjust each record to reflect reported annual electricity use.

Since BLAST-derived air conditioning energy use estimates were not calibrated to CBECS energy use or monthly billing information (see the section below), one would expect the CBECS air conditioning EUI's to be more accurate, *a priori*. However, an even more accurate estimate of each of the CBECS buildings air conditioning energy use can be developed reasonably easily as indicated in the next section.

4.4.3 Preferred Methodology for Estimating CBECS A/C Use

The fifteen months of billing data (kWh and peak kW) which exists for most 1995 CBECS records can be used to estimate air conditioning EUIs (including fan use) for each record. Ordinary least square regressions can be run using monthly kWh- and kW-dependent variables (a technique called "seemingly unrelated regression" can be used to combine the two estimations and improve the estimation efficiency) and with weather variables, square feet, operating hours and other variables as independent variables. This regression technique has been used for more than twenty years as a first step in audit analysis where a building's kWh and kW are separated into "weather-sensitive" and "non-weather sensitive" energy use. Applying this process to CBECS records would establish the extent to which BLAST over-estimates air conditioning EUI's, if that is, in fact, the case.

It should be noted that this statistical decomposition of weather- and non-weather-sensitive loads takes into account the use of both air conditioning and space heating in some months. This approach will provide a more accurate estimate of air conditioning energy use compared to that reported in the CBECS records, because the CBECS process had to calibrate to space heating air conditioning and other end uses while the statistical process can be specified to provide a primary estimate of air conditioning.

This process should also be undertaken in support of the following improvement in BLAST modeling. (See ASHRAE Guideline 14-2002 for procedures.)

4.4.4 Calibrating the BLAST Model to individual buildings

The micro-simulation modeling process that applies the BLAST model to a sample of actual buildings has many advantages, including the direct representation of the diversity of buildings in the population along with the minimization of aggregation error which tends to accompany analysis of prototype-based analysis.

This focus is clear in Chapter 6 of the documentation (Section 6.2.3.2): *"In this analysis, DOE transformed the loads and energy use for systems defined with the generic building's geometry to provide loads and energy use for an actual CBECS building used for the analysis. This is because the analysis reported in this document requires development of system loads representative of an actual building, not a typical building."*

The BLAST modeling, while incorporating information from each building record in each simulation, completely ignores by far the most important opportunity to develop "*system loads representative of an actual building, not a typical building"* when it fails to calibrate the BLAST simulation for each building to monthly billing data and estimated air conditioning kWh and peak kW contributions (see section above).

The comparison of BLAST air conditioning EUI's and CBECS EUI's (as a proxy, at this point, for actual EUI's) presented by DOE (Figure 6.3.1 below) shows little correlation. Assuming that the CBECS EUI's are just moderately accurate suggests that the BLAST model output for each record bears little relationship to the actual air conditioning electricity used by the building. Most of the dots in Figure 6.3.1 should lie around the line extending to the upper right in the Figure.

Each of the buildings modeled with BLAST should have been calibrated using the building's actual monthly billing data and statistically-based estimates of air conditioning electricity use. While this calibration requires a series of heuristic decision rules, the end result is far preferable to what was accomplished with the current analysis. For instance, if the BLAST simulation of a CBECS record shows 30% more air conditioning electricity use than what is consistent with monthly billing data and statistically-based air conditioning electricity use, we don't know to what extent the discrepancy is a function of insulation levels, ventilation rates, thermostat setting, occupancy or other factors. However, calibrating to actual air conditioning electricity use by modifying some of these parameters provides a modeled record that at least has the correct air conditioning electricity use. Decision rules can be altered and sensitivity analysis can be run to determine the impact of these rules on the analysis results. To the extent that the decision rules are formalized, parameter searches can be performed providing an estimation result consistent with Maximum Likelihood Estimation.

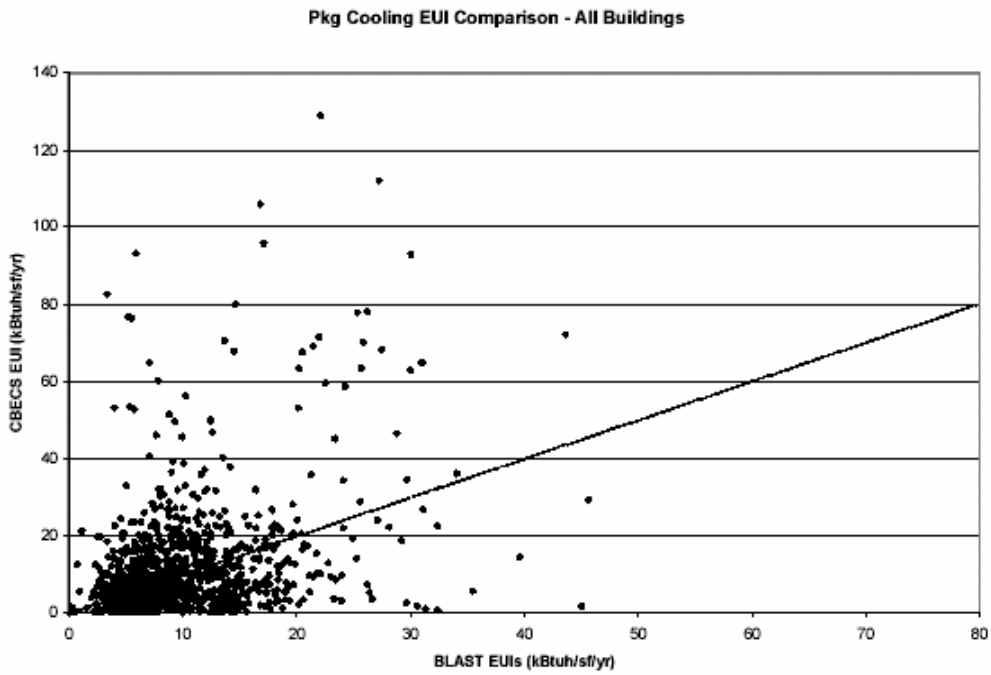

Figure 6.3.1 Plot of CBECS Estimated EUIs versus BLAST EUIs

Results shown in another Figure (6.3.3), which aggregates result for the six building types and climate regions, is used by DOE as the basis for the following statement: "*It appears that, when the results are smoothed by aggregating the EUIs into a small number of groups consisting of many buildings, the correlation between the two data sets becomes more favorable, lending credibility to the simulation methodology*." This statement is simply not correct. While the dots fall along the diagonal line in this chart, these aggregate results reflect only the fact that the BLAST results show greater air conditioning use in hotter climates and greater air conditioning for the appropriate building types. These results do not validate the BLAST analysis when such large individual building discrepancies exist.

Ignoring the BLAST/actual EUI discrepancies ignores valuable information in the analysis process and elevates the argument of exactly offsetting errors to be a cornerstone of the BLAST analysis. This process turns the advantages of the sample-building-based micro-simulation analysis on its head. Micro-simulation provides more accurate results in part because analysis of a large number of individual buildings is more accurate than analysis of a few prototypes. The DOE analysis seems to argue that less accurate analysis of the individual buildings will lead to a more accurate final analysis.

4.4.5 Summary

The basic methodological framework of applying an engineering heat load model to individual CBECS building records is a significant improvement over previously applied analytical approaches. However, the current application of this methodology is seriously flawed with respect to the sampling requirements of this methodology as well as its failure to calibrate BLAST to the individual building records.

The impact of these deficiencies, which may be significant, can be corrected with the suggestions provided above. Determining the size and nature of the errors resulting from these analysis problems can only be determined empirically by incorporating the suggestions offered above. However, a relatively simple statistical analysis of CBECS data can determine the size of the error in BLAST-estimated air conditioning electricity use (see the section above entitled *Preferred Methodology for Estimating CBECS AC Use*).

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5.0 VENTILATION MODELING

5.1 Introduction

This section reviews the methodology used in the TSD for BLAST modeling of indoor ventilation, use of ventilation fans, and ventilation standards that should be applied the building models. The issues raised in stakeholder comments include questions about the airflow calculations used in BLAST and the application of ASHRAE Standard 62-2001 in setting minimum ventilation rates for commercial buildings.

5.2 Assessment

5.2.1 Airflow calculations in BLAST appear to be correct

One of the criticisms from Lennox (2003) regarding the BLAST energy use calculations of rooftops is that they were concerned that BLAST was overestimating fan power because of potential double counting the fan power. Because fan power is continuous during occupied hours, double counting it would increase total cooling energy use significantly. The IRT examined BLAST and it appears to be calculating airflow correctly *if* the rooftop data are input correctly. What is particularly crucial for correct calculation of power input is the value of condenser U-factor (CUA). This variable was discussed earlier in the context of the saturated condensing temperature (SCT). CUA is determined from detailed manufacturer's performance data on a unit. These performance data must not include indoor (evaporator) fan power in the power data. If this CUA is used, then the correct power (without indoor fan) for the rooftop will be calculated in BLAST and airflow power will not be doubled counted. This is a subtle point in the BLAST input file, but must be followed.

5.2.2 Ventilation Rates

ASHRAE 62-2001 is a default standard in the United States regulating ventilation rates for new construction. However, unless this standard has been adopted by local municipal building codes, it does not have the same legal standing as "code". The ventilation rates used by DOE and as shown in Table 6.2.2.1, Peak Ventilation Values Used in Various Analyses, are aggressive. As with the application of low-e glass in commercial construction, informed owners are going to ask for Demand Controlled Ventilation (DCV) or take advantage of scheduled ventilation for buildings with known and regular occupancies and schedules. DCV uses CO_2 concentration in a conditioned space as a surrogate for occupancy. If the CO_2 concentration is high, that indicates a correspondingly high occupancy rate, and the HVAC equipment will adjust to deliver the appropriate amount of fresh outdoor air. Scheduled ventilation is obtained through simple control of outside air dampers from minimum to "design" based on the building's occupancy schedule.

In our experience, many consulting engineers would agree that this is not the usual case and that the less informed owner will opt for the fixed rate of ventilation air. BLAST only seems to allow for either a fixed percentage or a fixed volume of outside ventilation air. The only other way that

outside air is modeled is through the use of an economizer option. Demand-, or especially occupancy-controlled ventilation could be modeled by applying a schedule modifier to the fixed volume input in BLAST. This option might require the modification of the BLAST code.

A high ventilation rate can place an enormous operational burden on smaller (7.5 ton) systems. A very common "rule of thumb" for commercial construction is that the total cooling flowrate is approximately 1.0 cfm/ft^2. Thus, the assembly area listed with a ventilation airflow rate at 0.89 cfm/ft^2 means that 89% of the total air flow is ventilation or fresh outside air. Particularly in southern climates, most commercial rooftop packaged equipment cannot accommodate the additional moisture load with this much ventilation. A value of 0.45 cfm/ft^2 was used for education facilities. This represents almost half of the total airflow for a nominally sized unit. Again, these ventilation rates, while meeting the intent of ASHRAE 62, are not necessarily strictly adhered to in practice. Additionally, smaller packaged systems do not have the dehumidification capacity to meet coincident cooling and ventilation loads.

It is not clear why the DOE uses CBECS occupancy data for office buildings in the building cooling and heating loads analysis, but goes on to use occupancy levels from Table 2 of the ASHRAE Standard 62-2001 for ventilation analysis. It would seem more prudent to use actual occupancy data for any buildings that are available in the CBECS database. Use of the Tabular data is the most conservative value and would overestimate the amount of ventilation required for those buildings.

5.3 Summary

The IRT concludes that the BLAST airflow calculations in the DOE TSD are done correctly. However, the ventilation rates used by DOE in its models correspond to an overly-aggressive and unrealistic application of the new ASHRAE Standard 62-2001 to the Nation's commercial buildings. The BLAST simulations should be re-done using lesser rates of ventilation.

6.0 ASSESSMENT OF THE INCREMENTAL MARKUP OF COMMERCIAL UNITARY AIR CONDITIONING EQUIPMENT PRICES

6.1 Introduction

As a result of numerous stakeholder comments, DOE requested that the IRT review the procedures used in the TSD to estimate the incremental markup of A/C prices for higher efficiency units.

This portion of the analysis was focused on the following issues:

- Are the assumptions used to calculate the equipment markups consistent with the existing practice in the industry, and is there any research in published literature that would support or challenge DOE's assumptions?
- Would a change in assumptions or data have a significant impact on the results of the analysis?
- Are there important areas of uncertainty that could have a significant impact on DOE's conclusions, based on a sensitivity analysis?
- Are there other cost factors outside of the scope of DOE's analysis that could have a significant impact, such as regional variations in costs or significant code or siting issues in states or localities that represent significant shares of the market?
- Are there economic implications DOE may have overlooked, such as an uneven distribution of the costs among national accounts, large mechanical contractors and small mechanical contractors? Uneven distribution of the costs between different regions or states?

The review considered the data and methods behind the following key assumptions and calculations:

- 30% of sales are for new installations
- 70% of sales are to replace old equipment

At each stage the markup has two components:

- Baseline markups are a function of the cost of equipment and are the revenue per dollar cost of goods required to cover all costs and profit
- Incremental markups are a function of the increase in the cost of equipment and only include the variable costs of a firm – all costs excluding labor and occupancy in this analysis

For 70% of sales involving replacement units:

- 82.5% sold through wholesalers, baseline markup of 1.36, incremental of 1.11
    - 50% of replacement sold through small mechanical contractors, baseline markup of 1.7, incremental markup of 1.37
    - 32.5% of replacement sold through large mechanical contractors, baseline markup of 1.55, incremental markup of 1.29

    - 82.5% that passes through mechanical contractors also passes through a general contractor, baseline markup of 1.24, incremental markup of 1.13.
- 17.5% of replacement sold through national accounts, ½ of normal distribution chain markup at 1.71

For 30% of sales involving new construction:

- 50% of new sold through small mechanical contractors, baseline markup of 1.48, incremental markup of 1.26
- 32.5% of new sold through large mechanical contractors, baseline markup of 1.35, incremental markup of 1.18
- 17.5% of new sold through national accounts, ½ of normal distribution chain at 1.80
- No general contractor involvement, and therefore no general contractor markup

6.2 Review of Assumptions and Approach Used to Calculate Markups

The IRT has reviewed the methodology and assumptions and has not found any information that would directly challenge DOE's analysis of the distribution channels for unitary air conditioning equipment. The literature search conducted for this stage of the analysis has not uncovered any comparable information that would undermine DOE's basic assumptions. DOE's analysis is characterizing the industry on a national basis. Other studies and data sources only deal with portions of the distribution channels and markets for equipment, and have not been comparable. DOE's choice of national data from the industry and the Census Bureau appears to be the best choice for this analysis because of the need for markup calculations based on consistent definitions and roughly comparable data sets in terms of the time frame the data covers and clear distinctions between the steps in the distribution chain that are being characterized. Other data sources or approaches considered would involve difficulties in trying to combine information from multiple sources involving different assumptions and source data.

The IRT examined the tables in Appendix L of the DOE analysis in detail to review the logic of the data included in the incremental cost markup calculations. The approach described in the analysis was applied consistently. All labor-related costs were excluded from the calculation of incremental markups, while all other costs were included in the incremental markup calculations.

Although there are no data to back up the estimate of the markup on national accounts, the logic of the argument that it would fall somewhere between the manufacturer's price for the equipment and the price to a customer using one of the other distribution chains is logical. Splitting the difference and taking half is somewhat arbitrary, but there is not enough data to create a better estimate.

6.3 Potential Impact of Manufacturing/Industrial Sales on Markup Calculations

A potentially important factor in the market analysis is addressed in Section 3.3 of this report: to what extent sales to the industrial sector is an important factor that should be included in the economic impact analysis of the new rule. For the markup analysis the main issue this raises is whether sales to the industrial sector break down into the same proportions of new and replacement units, and from there into the same proportions with regard to shares sold through

wholesalers versus national accounts, and from wholesalers to large and small mechanical contractors. There is no literature that would argue for changing the proportions, and based on the analysis in Section 3.3 the best assumption is that the supply chains would remain unaltered as far as the proportions of new and replacement sales, and how the equipment is distributed. Light industrial customers and the types of commercial buildings served by these types of unitary air conditioning units involve similar construction practices and similar contractor arrangements. The current description of the distribution chains is practical for both.

6.4 Sensitivity Analysis of Changes in Markup Assumptions

This element of the review focuses on whether a change in markup assumptions would have a significant impact on the results of the analysis. To accomplish this the markup estimates were varied based on the distribution analyses of the markups, and then the changes were input into the Life Cycle Cost impact analysis spreadsheets used in the DOE analysis. The range of markups tested was limited to values within two standard deviations of the national averages developed in the report. This was chosen as one bound on the variability of the markup calculations. Assuming a normal distribution, using a value two standard deviations from the mean in effect picks a value at the high end of the distribution of values used to calculate the mean, a value that is at the outer limits of 95% of the values within the distribution. The only exception was for the wholesaler incremental markup, where the probability distribution used in the original analysis was truncated to avoid having a markup less than zero. In this case a markup at the level of the mean plus .82 standard deviations was used, to parallel the assumption used in the original analysis. The original markup assumptions and the values used in the sensitivity tests are shown in Table 6.1. The net result was an increase in the overall baseline markup of 24% and an increase in the overall incremental markup of 15%.

Table 6.2 shows some of the results of the change in markup levels for the changes described above, for an extreme case in which the original overall baseline and incremental markup were doubled, and for a doubling of the overall baseline markup. The "Engineering" tab in the lcc_cuac_tariff.xls workbook developed for the original analysis in Chapter 7 of the TSD was used to calculate the values in the table. Note that except for the values in the last two columns, which only use the baseline multipliers, the values for equipment price are a function of both the baseline and incremental markup values applied to the manufacturer price and cost. So while the relationship between manufacturer price and equipment price in Table 6.2 are derived from the values in Table 6.1, the multipliers have to be applied to both the manufacturer price (baseline) and the differences in manufacturer costs (incremental) to arrive at equipment price. For example the value for the 7.5 ton unit at the EER10.5 efficiency level is derived from multiplying the price of the baseline unit used for comparison ($2098) times the baseline markup for new construction (2.66) for a value of $5,586. The incremental markup is derived by multiplying the difference in price between the baseline unit and the EER10.5 unit ($2,145 - $2,098=$47) which is then multiplied by the new construction markup for small mechanical contractors (1.68 * $47 = $79). Adding the incremental calculation to the baseline calculation arrives at the markup price of $5,665. The new construction markups are the highest in the distribution chain, so these sensitivities are the highest levels of equipment costs used in the analysis. Other markups would be lower.

The sensitivity markups increase the price of the 7.5 ton units between $1,796 and $2,004, and the price of the 15 ton units between $3,387 and $3,799. However, the change in the price differential between the baseline unit (EER 10.1 for the 7.5 ton unit and EER 9.5 for the 15 ton unit) is a maximum of $208 for the 7.5 ton unit and a maximum of $380 for the 15 ton unit. The differentials in price are the main drivers for differences in life cycle costs, payback period and the economic and energy indicators used in the analysis. Because the price differentials between the baseline unit and the high efficiency units are relatively small even at the higher limits of the likely distribution of markups, pursuing greater accuracy in the markups is unlikely to have much impact on the overall analysis. The small price differentials are a product of the fact that the markups are applied to derive the price of the baseline units as well as the higher efficiency units. Therefore, changes in the markups result in only minor changes in the price difference between units. The price differentials are more sensitive to the incremental markups because they are not applied to the baseline units – they are driven completely by the difference in price between the baseline units and the higher efficiency units.

As shown in the last column of Table 6.2, doubling the overall baseline markup only creates a price differential of $704 for the 7.5 ton EER12 unit, and $1,283 for the 15 ton EER 12 unit. There is no indication that the baseline markup estimates are off by anywhere near that large an amount. Doubling both the incremental and baseline overall markup creates larger price differences, up to $1,616 for the 7.5 ton unit and $2,947 for the 15 ton units. Incremental markups that are off by a factor of two are even less likely than the baseline markup doubling. The lifecycle cost spreadsheets for both the hourly and tariff electricity price models were run several times with both the original and the sensitivity analysis markups using the Crystal Ball 2000 forecasting features. None of the runs turned up consistent, significant shifts in the original analysis results.

Table 6.1: Original Markups and Markups Plus Two Times Standard Deviation

Original Markups for Commercial Unitary A/C and Heat Pumps

	NEW CONSTRUCTION			REPLACEMENT			OVERALL
	Baseline			Baseline			Baseline
	Small Mech.	Large Mech.	Nat. Acct.	Small Mech.	Large Mech.	Nat. Acct.	
Distributor	**1.36**	**1.36**	**1.69**	**1.36**	**1.36**	**1.60**	1.41
General Contractor	1.24	1.24	1.00	1.00	1.00	1.00	1.06
Mech. Contractor	1.48	1.35	1.00	1.70	1.55	1.00	1.48
Sales Tax	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Overall	2.66	2.42	1.80	2.47	2.24	1.71	2.31

	NEW CONSTRUCTION			REPLACEMENT			OVERALL
	Incremental			Incremental			Incremental
	Small Mech.	Large Mech.	Nat. Acct.	Small Mech.	Large Mech.	Nat. Acct.	
Distributor	**1.11**	**1.11**	**1.27**	**1.11**	**1.11**	**1.24**	1.13
General Contractor	1.13	1.13	1.00	1.00	1.00	1.00	1.03
Mech. Contractor	1.26	1.18	1.00	1.37	1.29	1.00	1.25
Sales Tax	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Overall	1.68	1.59	1.35	1.63	1.53	1.32	1.56

Sensitivity Markups for Commercial Unitary A/C and Heat Pumps

	NEW CONSTRUCTION			REPLACEMENT			OVERALL
	Baseline			Baseline			Baseline
	Small Mech.	Large Mech.	Nat. Acct.	Small Mech.	Large Mech.	Nat. Acct.	
Distributor	**1.58**	**1.58**	**1.69**	**1.58**	**1.58**	**1.86**	1.62
General Contractor	1.34	1.34	1.00	1.00	1.00	1.00	1.08
Mech. Contractor	1.57	1.43	1.00	1.80	1.64	1.00	1.55
Sales Tax	1.06	1.06	1.06	1.06	1.06	1.06	1.06
Overall	3.52	3.20	1.79	3.02	2.75	1.97	2.86

	NEW CONSTRUCTION			REPLACEMENT			OVERALL
	Incremental			Incremental			Incremental
	Small Mech.	Large Mech.	Nat. Acct.	Small Mech.	Large Mech.	Nat. Acct.	
Distributor	**1.20**	**1.20**	**1.27**	**1.20**	**1.20**	**1.35**	1.22
General Contractor	1.22	1.22	1.00	1.00	1.00	1.00	1.05
Mech. Contractor	1.33	1.26	1.00	1.46	1.37	1.00	1.32
Sales Tax	1.06	1.06	1.06	1.06	1.06	1.06	1.06
Overall	2.06	1.95	1.34	1.85	1.74	1.43	1.79

Increase in Baseline Markup	24%
Increase in Incremental Markup	15%

Table 6.2: Equipment Price Impacts of Changes in Markups

	System = 7.5-ton unit								
Descrip.	Manuf. Price ($2001)	Equip. Price ($2001) Original	Equip. Price ($2001) Sensitivity	Price Difference with Sensitivity	Change in Price Differentials Sensitivity	Equip. Price ($2001) 2* both Markups	Change in Price Differentials 2* Both Markups	Equip. Price 2* Baseline	Change in Price Differentials 2* Baseline
EER=9.5	$2,098	$5,586	$7,382	$1,796		$11,173		$11,173	
EER=10.0	$2,098	$5,586	$7,382	$1,796	$0	$11,173	$0	$11,173	$0
EER=10.1	$2,098	$5,586	$7,382	$1,796	$0	$11,173	$0	$11,173	$0
EER=10.5	$2,145	$5,665	$7,479	$1,814	$18	$11,331	$140	$11,252	$61
EER=11.0	$2,237	$5,821	$7,670	$1,849	$53	$11,641	$415	$11,407	$181
EER=11.5	$2,390	$6,077	$7,985	$1,908	$112	$12,153	$868	$11,663	$378
EER=11.8	$2,525	$6,305	$8,264	$1,960	$164	$12,609	$1,272	$11,891	$554
EER=12.0	$2,641	$6,499	$8,503	$2,004	$208	$12,997	$1,616	$12,085	$704

	System = 15-ton unit								
Descrip.	Manuf. Price ($2001)	Equip. Price ($2001) Original	Equip. Price ($2001) Sensitivity	Price Difference with Sensitivity	Change in Price Differentials Sensitivity	Equip. Price ($2001) 2* both Markups	Change in Price Differentials 2* Both Markups	Equip. Price 2* Baseline	Change in Price Differentials 2* Baseline
EER=9.5	$3,957	$10,537	$13,924	$3,387		$21,073		$21,073	
EER=10.0	$4,019	$10,641	$14,052	$3,411	-$8	$21,282	-$60	$21,178	-$26
EER=10.1	$4,039	$10,675	$14,094	$3,419	$0	$21,350	$0	$21,212	$0
EER=10.5	$4,122	$10,813	$14,264	$3,450	$32	$21,627	$245	$21,350	$107
EER=11.0	$4,291	$11,098	$14,613	$3,515	$96	$22,195	$749	$21,634	$326
EER=11.5	$4,570	$11,566	$15,188	$3,622	$203	$23,132	$1,578	$22,103	$688
EER=11.8	$4,823	$11,993	$15,713	$3,720	$301	$23,985	$2,334	$22,529	$1,017
EER=12.0	$5,029	$12,338	$16,137	$3,799	$380	$24,677	$2,947	$22,875	$1,283

6.5 Other Markup Cost Factors

This portion of the markup review examines whether there are other cost factors outside of the scope of DOE's analysis that could have a significant impact, such as regional variations in costs or significant code or siting issues in states or localities that represent significant shares of the market. Information on state variations in markup estimates is included in Appendix L of the DOE analysis and was used in calculating the distribution and standard deviation of markups at the wholesaler, mechanical contractor and general contractor elements of the distribution chain.

As Appendix L reports, the relative standard deviation in the wholesale baseline markup is 8.2%; the general contractor relative standard deviation is 3.9%; and the mechanical contractor relative standard deviation is 3.1%. The frequency distribution for the markup values is fairly tight. The state data in Appendix L on wholesale baseline markups (Table L.5.1), general contractor baseline markups (Table L.5.2), and mechanical contractor markups (Table L.5.3) was used during this review to examine whether there were significant variations in markup levels by state.

These data have several limitations that obstruct a direct comparison with the original analysis. First, they do not include the level of detail needed to break the mechanical contractors down into small and large within each state. Second, many states are missing information for one or

all of the tables. This did not affect the original analysis because it used the average values for wholesale, general contractor and mechanical contractors, but it precludes developing overall markups by state that are directly comparable to the original analysis. Still, 26 states had enough information to create rough estimates of the total baseline markup involving a wholesaler, a general contractor and a mechanical contractor to allow comparisons between states. As shown in Table 6.3, the average of the overall baseline markups calculated by state was 2.58; this is between the 2.42 and 2.66 overall markup calculated for new construction involving small and large mechanical contractors derived in the study. The standard deviation is 7.7%, or .2 as an absolute value.

The state baseline markups in Table 6.3 are arranged in ascending order, with the states with the lowest overall markups at the top of the table. The baseline markup calculations in this analysis and in the original study were not weighted or adjusted to account for potential differences in the level of sales through different state supply chains – they only use the average level of markup. There is a potential problem if states that account for a larger proportion of sales also have a higher than average markup level. First, these states could experience a disproportionate share of the economic impact of increased equipment costs caused by raising efficiency standards because they will experience higher prices. Second, the national average markups may be inaccurate because they mask important regional variations in markups.

To illustrate this issue, Table 6.3 also includes information on the proportion of total general contractor construction value attributed to each state in the census data used for the markup analysis. California accounts for the largest share of construction value in the census, at 9.4%, and has the third highest overall markup level. However, the California markup level is still only 8% higher than the average, which is within one standard deviation of the mean value. New Jersey and South Carolina are the only states with higher baseline markup levels, and together they account for only 4.7% of mechanical contractor sales. This indicated that some of the variations in the markup levels do occur in states with large equipment markets, but it gave little indication as to whether the differences were significant.

To examine whether these differences might have made a significant difference in the baseline markups, the baseline markup calculations for wholesalers, general contractors and mechanical contractors were recalculated by weighting each state's markup by its share of overall national sales. Table 6.4 summarizes the results of the weighting. The table is divided into sections for wholesale, general contractor and mechanical contractor markups. The first column in each section shows the markup calculation used in the original study. The second column shows the contribution that state's markup would make to a weighted calculation, the product of multiplying that state's share of national sales times its average state markup. When the weighted calculations are added together and compared to an average of the state markups, the results show a very small, less than 1%, difference between the two approaches. The conclusion is that the approach used to estimate baseline markups may have masked some variation in markup levels from state to state, but the differences are very small and would not affect the overall conclusions of the analysis or result in significant state-level differences.

Table 6.3: State Markup Calculations

States with Available Data	Wholesale Baseline Markup	General Contractor Baseline Markup	Mechanical Contractor Baseline Markup	Sales Tax	Overall Markup	Proportion of Value of Construction, General Contractor
Oregon	1.23	1.17	1.38	1.06	2.11	1.55%
Maryland	1.24	1.26	1.39	1.06	2.30	3.10%
Colorado	1.34	1.16	1.41	1.06	2.32	1.94%
Arizona	1.3	1.18	1.43	1.06	2.33	1.79%
Tennessee	1.35	1.17	1.4	1.06	2.34	2.22%
Missouri	1.36	1.13	1.46	1.06	2.38	2.12%
Virginia	1.34	1.2	1.42	1.06	2.42	2.42%
Wisconsin	1.24	1.27	1.48	1.06	2.47	2.42%
Michigan	1.31	1.22	1.48	1.06	2.51	3.83%
Louisiana	1.35	1.23	1.47	1.06	2.59	1.18%
Texas	1.39	1.24	1.43	1.06	2.61	6.86%
Indiana	1.36	1.26	1.44	1.06	2.62	2.77%
New York	1.38	1.21	1.48	1.06	2.62	6.06%
Alabama	1.35	1.2	1.53	1.06	2.63	1.41%
Arkansas	1.32	1.27	1.48	1.06	2.63	0.67%
Illinois	1.39	1.21	1.48	1.06	2.64	5.35%
Kentucky	1.36	1.25	1.47	1.06	2.65	1.23%
Ohio	1.39	1.25	1.44	1.06	2.65	4.41%
Minnesota	1.48	1.18	1.45	1.06	2.68	2.00%
Florida	1.44	1.23	1.45	1.06	2.72	4.89%
Connecticut	1.42	1.21	1.5	1.06	2.73	1.15%
North Carolina	1.47	1.2	1.47	1.06	2.75	3.43%
Washington	1.49	1.16	1.52	1.06	2.78	2.17%
California	1.51	1.21	1.45	1.06	2.81	9.37%
New Jersey	1.4	1.35	1.46	1.06	2.92	3.22%
South Carolina	1.5	1.33	1.39	1.06	2.94	1.36%
Wyoming			1.42	1.06		0.15%
Vermont			1.49	1.06		0.17%
South Dakota			1.41	1.06		0.20%
Alaska			1.49	1.06		0.22%
North Dakota	1.85		1.44	1.06		0.26%
Rhode Island			1.4	1.06		0.28%
Montana	1.44		1.36	1.06		0.28%
Hawaii			1.55	1.06		0.30%
Maine		1.27	1.46	1.06		0.31%
West Virginia			1.4	1.06		0.35%
New Hampshire			1.44	1.06		0.42%
New Mexico			1.38	1.06		0.45%
Delaware			1.53	1.06		0.47%
Idaho			1.43	1.06		0.61%
Mississippi		1.21	1.45	1.06		0.64%
Nebraska			1.43	1.06		0.67%
Oklahoma	1.35		1.52	1.06		0.85%
Nevada		1.64	1.42	1.06		1.01%
Utah		1.19	1.49	1.06		1.03%
Iowa		1.21	1.51	1.06		1.08%
Kansas			1.41	1.06		1.14%
Massachusetts			1.42	1.06		2.52%
Georgia	1.36		1.5	1.06		3.10%
Pennsylvania		1.24	1.46	1.06		4.58%
National Markup	1.390	1.222	1.451		2.58	

Table 6.4: State by State Comparison, Markups Weighted by Share of Total Sales Versus Averaged Markup

	Wholesale		General Contractor		Mechanical Contractor	
	Baseline Markup	Contribution to Baseline Markup, Weighted by Share of Total Sales	Baseline Markup	Contribution to Baseline Markup, Weighted by Share of Total Sales	Baseline Markup	Contribution to Baseline Markup, Weighted by Share of Total Sales
Alabama	1.35	0.034	1.2	0.0298	1.53	0.0215
Alaska					1.49	0.0033
Arizona	1.3	0.029	1.18	0.0256	1.43	0.0255
Arkansas	1.32	0.012	1.27	0.0136	1.48	0.0100
California	1.51	0.126	1.21	0.1469	1.45	0.1358
Colorado	1.34	0.022	1.16	0.0321	1.41	0.0273
Connecticut	1.42	0.018	1.21	0.0168	1.5	0.0172
Delaware					1.53	0.0072
Florida	1.44	0.120	1.23	0.0682	1.45	0.0709
Georgia	1.36	0.063			1.5	0.0465
Hawaii					1.55	0.0047
Idaho					1.43	0.0087
Illinois	1.39	0.059	1.21	0.0623	1.48	0.0791
Indiana	1.36	0.043	1.26	0.0274	1.44	0.0398
Iowa		0.000	1.21	0.0123	1.51	0.0163
Kansas					1.41	0.0160
Kentucky	1.36	0.025	1.25	0.0131	1.47	0.0180
Louisiana	1.35	0.030	1.23	0.0126	1.47	0.0174
Maine			1.27	0.0026	1.46	0.0045
Maryland	1.24	0.031	1.26	0.0431	1.39	0.0431
Massachusetts					1.42	0.0357
Michigan	1.31	0.055	1.22	0.0387	1.48	0.0567
Minnesota	1.48	0.031	1.18	0.0335	1.45	0.0290
Mississippi			1.21	0.0144	1.45	0.0093
Missouri	1.36	0.029	1.13	0.0345	1.46	0.0309
Montana	1.44	0.003			1.36	0.0039
Nebraska					1.43	0.0096
Nevada			1.64	0.0261	1.42	0.0143
New Hampshire					1.44	0.0060
New Jersey	1.4	0.052	1.35	0.0396	1.46	0.0470
New Mexico					1.38	0.0062
New York	1.38	0.064	1.21	0.0926	1.48	0.0897
North Carolina	1.47	0.081	1.2	0.0435	1.47	0.0503
North Dakota	1.85	0.001		0.0000	1.44	0.0037
Ohio	1.39	0.061	1.25	0.0480	1.44	0.0634
Oklahoma	1.35	0.021		0.0000	1.52	0.0128
Oregon	1.23	0.032	1.17	0.0212	1.38	0.0213
Pennsylvania			1.24	0.0588	1.46	0.0669
Rhode Island					1.4	0.0039
South Carolina	1.5	0.031	1.33	0.0149	1.39	0.0189
South Dakota					1.41	0.0028
Tennessee	1.35	0.067	1.17	0.0306	1.4	0.0311
Texas	1.39	0.142	1.24	0.1053	1.43	0.0980
Utah			1.19	0.0170	1.49	0.0153
Vermont					1.49	0.0026
Virginia	1.34	0.044	1.2	0.0370	1.42	0.0343
Washington	1.49	0.033	1.16	0.0330	1.52	0.0330
West Virginia					1.4	0.0049
Wisconsin	1.24	0.029	1.27	0.0300	1.48	0.0357
Wyoming					1.42	0.0021
Overall	1.39	1.388	1.222	1.2251	1.4514	1.4519
% Difference, Weighted versus Average		-0.20%		0.29%		0.03%

The analysis also considered whether the proportion of sales going through the distribution chains is the same from state to state and region to region, and whether variations might have a significant impact. In areas where for some reason markups tend to be higher than the national average there might be a tendency for customers to favor one distribution chain over another or, more likely, for customers served by a more expensive distribution chain to delay replacement. At this point there are no means of testing whether there are significant variations because the wholesaler and contractor data also include their work with other types of equipment. However, based on analyses of the state-specific information on markups in Appendix L, the IRT sees no major disparities that would encourage a significant shift in how unitary air conditioning equipment sales are made in any particular states.

There may be a related issue at the national level that DOE should consider – whether a change in the price of equipment at the manufacturer may shift the proportion of sales for new versus replacement equipment, and/or shift the proportion of sales made through the different distribution chains. For systems going into new construction the markup on equipment is unlikely to change the distribution chain; the contractors are involved in far more than installing the air conditioning unit and are not likely to be chosen primarily because of the cost of the unit they propose. However, the replacement market may change as a result of increased equipment costs, as customers may delay replacements longer than under current conditions, and those at the end of the distribution chains with the highest markup may be more inclined to delay. That would affect overall sales and revenue, but it could also mean a disproportionate impact on the small mechanical contractors who tend to be in the distribution chain with the highest markups. That issue falls outside of the review of the markup analysis, but is worth considering in the overall impact analysis for the rule.

On the issue of siting or code issues associated with unitary air conditioning equipment that meets the new efficiency standards, we have found no evidence that the new standards would result in a significant change in the way the equipment operates or in its dimension and sizes that would affect how it is sited or the required permitting.

6.6 Summary

The review of the markup calculations used in the original analysis found no major flaws in the approach. The IRT also found that because of the way the markups are applied to both the baseline units used for comparison and the higher efficiency units, there would have to be unrealistically large errors in the magnitude of the markup estimates to have any significant impact on the conclusions of the study. There is no indication that the markup calculations should change that much. Finally, while the averaging of state data on markups used in the original study masks some state-level variations in markup levels and therefore in the impacts of higher efficiency standards from state to state, the variations do not appear to be significant enough to have a major effect on the conclusions of the DOE analysis.

7.0 SUMMARY CONCLUSIONS AND RECOMMENDATIONS

The Independent Review Team (IRT) was charged with reviewing the analyses in support of the ANOPR for setting energy efficiency standards for commercial unitary air conditioners and heat pumps in the range of 65,000 to 240,0000 Btu per hour cooling capacity (the Technical Support Document – TSD) and selected stakeholder comments and analyses. The objectives of the independent review were to assess the analytical processes used and comment on:

- The reasonableness of assumptions that were made;
- The overall logic of the methodology;
- The quality of the data and data analysis/simulation tools that were used; and
- The validity of issues that have been raised with the analysis by stakeholder comments.

To support a more stringent standard than ASHRAE 90.1-1999, the DOE analysis must show that such a standard is technically feasible and economically justified. This requires:

- Identifying which facilities will be affected by the proposed rulemaking;
- Determining the electricity consumed by the covered appliances, with and without the proposed rulemaking;
- Estimating the energy and operating cost savings that would result from the standard; and
- Estimating the incremental markup of prices of more efficient air conditioners.

Such analyses require data, assumptions and approximations, analysis procedures (including energy use simulation models), and life cycle cost analysis. This is not a precise process; competent professionals can differ on all aspects of this analysis. The IRT's role was not to re-do the DOE analysis but to judge whether it was reasonable and defendable; whether there were errors that should be corrected; and/or whether there were better procedures, data or models to perform the analysis. Where the team concluded that an error had been made or there was a better alternative analysis procedure, we tried, at least qualitatively, to determine whether the proposed modification was likely to significantly affect the results of the TSD. The IRT was specifically asked to look at four areas:

- The use of a subset of the CBECS 1995 database to characterize unitary A/C use and costs in buildings;
- The procedures used to estimate the amount of electricity used for A/C, especially the use of the BLAST model applied to building types indicated by the CBECS data;
- The modeling of ventilation in the subject buildings; and
- The estimation of incremental price increase for more efficient A/C units.

Sections 3.0 through 6.0 have described these issues, the analysis procedures used by the IRT, and our conclusions. This section summarizes those conclusions and, in the Appendix to 7.0, lists the documents received by the IRT from DOE to carry out the assessment.

Table 7-1 – Summary of IRT Conclusions

Sect.	Issue	Recommendation	DOE Effort Required	Effect On TSD Conclusions
III	**CBECS**			
3.2	Use of CBECS 1995	IRT agrees with use of CBECS 1995. There is no more appropriate data base. Relevant commercial facilities are adequately represented.	None	N/A
3.3	Exclusion of industrial facilities	Additional assessment of this issue is warranted, to determine the magnitude of energy used by unitary A/C in industrial facilities with significantly lower electric rates. IRT feels this, if significant, is likely to be less significant than suggested in the stakeholder comments.	Moderate	− Possibly significant
3.4	Modeling multi-building facilities	IRT feels this is not a significant factor in the TSD analysis.	None	Not significant
3.5	Sample distribution	The 1,033 building sample adequately represents the distribution of commercial buildings by region and climate.	None	N/A
3.6	Unitary A/C not primary	The IRT feels no additional modeling is needed to specifically include those instances where the unitary A/C is not the primary HVAC system	None	N/A
IV	**BLAST modeling**			
4.2.1	Single compressor model, no part load cycling	Large portion, if not most, of the covered units now use multiple compressors and perform much more efficiently than BLAST predicts. Recommend developing updated multi-compressor and part load cycling compressor models for BLAST	Extensive effort to develop and test model	− Significant
4.2.2	High temp. for head pressure controls	Determine more accurate minimum saturated condensing temperature and re-run BLAST simulations	Moderate	? Significant
4.2.3	Condenser U-factor	Default condenser U-factor value used gives unrealistically low saturated condensing temperature, significantly underestimating A/C energy use. Use correct CUA values and re-run BLAST simulations	Moderate	+ Significant
4.2.4	Saturated suction temperature	Default value of SST is too low (by about 5 degrees F). Obtain more accurate SST from manufacturers' data and re-run BLAST simulations.	Moderate	− Significant
4.2.5	Experimental verification	BLAST rooftop model has not been verified experimentally. While this does not invalidate the results, it leaves them vulnerable to challenge in a public hearing forum. IRT recommends experimental verification for A/C in each size class.	Significant	Unknown
4.2.6	A/C capacities simulated	Many of the BLAST simulations used A/C units outside of the 65 – 240 kBtu/h range. Re-zone the model buildings and re-run BLAST simulations..	Moderate	Unknown
4.2.7	Maximum commercial A/C efficiency	Maximum efficiency of commercially-available A/C is too low (max. EER of 12.0 used). Units with EER of 13.5 are available.	Minimal	Revise charts in TSD Chapter 8

4.2.8	Part load performance	BLAST cannot model many of the options available to commercial A/C units, such as multiple speed compressors and fans. This seriously underestimates expected efficiency of A/C units. A new model should be developed.	Extensive	− Significant
4.3.1	ASHRAE 90.1-1999 /2001 EERs	Correct labeling of ASHRAE Standard EER levels	Minimal	None
4.3.2	Low-e windows	TSD overstates use of low-emissivity glazing. Re-estimate and re-run BLAST simulations.	Moderate	+ Possibly Significant
4.3.3	Economizer	TSD overstates use of economizer. Remove economizer and re-run BLAST simulations.	Minimal to Moderate	+ Possibly Significant
4.4	BLAST simulations of CBECS cells	IRT feels the simulation of so many building types and climate zones within the1,033 building sample, and then extrapolating to draw national conclusions, may have introduced bias and aggregation error. A re-calculation of the weighting factors may be needed. This should be investigated.	Moderate to investigate.	Unknown, possibly significant
V.	**Ventilation**			
5.2.1	BLAST airflow	The IRT feels the BLAST airflow calculations are correct.	None	N/A
5.2.2	ASHRAE 62-2001	The higher ventilation rates required by ASHRAE Standard 62-2001 have been applied in the modeling more aggressively than they are applied in existing buildings. Reduce ventilation requirements and re-run BLAST simulations.	Minimal to Moderate	− Probably Significant
VI.	**Markup**			
6.2 – 6.5	Markup procedures	IRT sees no indication that the markup analysis should be modified.	None	N/A

Table Explanation:

The Table is a "checklist" of the issues examined by the Independent Review Team (IRT), not meant to take the place of each Chapter's more comprehensive conclusions/findings.

Column 1, **Sect.**, lists the section(s) in the report where the issue is covered.

Column 2, **Issue**, gives an abbreviated or keyword indication of the relevant issue(s). Sometimes several "points" were grouped together because they were related.

Column 3, **Recommendation**, gives the summary, conclusion and/or recommendation of the analysis related to each issue. This is a not an attempt to summarize all the ramifications of the analysis. It is a short answer to the question "What does the IRT's recommendation mean about the technical support document's (TSD) analysis?"

Column 4, **DOE Effort Required**, is the IRT's qualitative assessment of how extensive an effort it will be for DOE to comply with our recommendation; that is, to perform additional analyses, simulations, sensitivity analyses, etc.

Column 5, **Effect on TSD Conclusions**, is a *qualitative* assessment of how much the IRT thinks this issue will affect the results of the TSD.

- "**N/A**" (not applicable) where the IRT is recommending no additional or corrected analysis.
- "**Unknown**" means that without doing the analysis we don't know how big an effect this could have. That does not mean it is not potentially a large effect.
- "**Significant**" means that this correction or additional analysis will likely have a major effect on the results.

  + means that the recommended change will tend to favor more efficient A/C, more stringent standards. (E.g., such as when the change will result in the air conditioners modeled using *more* energy than currently shown by the TSD.)

  − means that the recommended change will tend to reduce the operating costs of A/C, showing less benefit from more stringent standards. (Such as when the change will result in the air conditioners modeled using *less* energy than currently shown by the TSD.)

  ? is used in one entry (4.2.2) where the IRT's recommended change will increase energy use in one way and decrease it in another; the net effect is not known.

The "Recommendation," "DOE Effort Required" and "Effect on TSD Conclusions" columns in the Table are an attempt to give a shorthand guide to the IRT's recommendations:

- DOE TSD analysis was fine, no change in TSD.
- DOE TSD analysis needs to be looked at more closely to see if potential inaccurate assumptions will have a significant effect on the results.
- DOE TSD analysis might be a little "off," but we don't think it's significant, probably resulting in small changes, if any, in TSD conclusions.
- DOE TSD analysis has a significant error or defect. Correcting it is important, will likely have a significant effect on the TSD conclusions, will require a (large/small) amount of effort, and the revised analysis will result in (more/less/unknown) justification for a stricter standard.

The IRT has identified a number of issues, problems or errors in the TSD analysis related to the building sample, BLAST simulations, and the markup analysis.

The foremost building sample issue is the omission of industrial buildings with unitary A/C systems. This requires some additional assessment.

Many of the BLAST-related issues should be resolved by obtaining more accurate modeling parameters (usually easy to obtain) and re-running the BLAST simulations. However, BLAST has some serious limitations in its ability to model modern A/C units, especially compressors and control options, that are being installed in the U.S. Correcting this requires development and validation of new A/C and component models or use of another simulation model. Such model development is a major undertaking, but more accurate modeling of the covered A/C is expected to have a significant effect on the TSD results.

The IRT sees no need to modify the DOE estimates of unitary air conditioner price markups.

Appendix to 7.0 Documents Received from DOE by the IRT

"Draft Advance Notice of Proposed Rulemaking and Notice of Public Hearing. Energy Conservation Program for Commercial and Industrial Equipment: Energy Conservation Standards for Commercial Unitary Air Conditioners and Heat Pumps," ANOPR-CUAC 06-30D-03 GJR-JDR v2EWORD, DOE (not published), received August 1, 2003.

"Draft Advance Notice of Proposed Rulemaking and Notice of Public Hearing. Energy Conservation Program for Commercial and Industrial Equipment: Energy Conservation Standards for Commercial Unitary Air Conditioners and Heat Pumps; Technical Support Document," DOE (not published).

Chapters 1, 2, 5, 6, 12, 13, 14, 15, 16	dated July 28, 2003
Chapter 3	dated June 17,2003
Chapter 4	dated March 20, 2003
Chapter 7	dated March 21, 2003
Chapter 8	dated July 21, 2003
Chapter 9	dated July 31,2003
Chapter 10	dated July 25, 2003
Chapter 11	dated January 22, 2003
Appendices E, F, G, H, I, J, K, L	dated November 21, 2002
Appendices M, N, O, P	dated December 4, 2002
Appendix Q	dated July 21, 2003

Lennox, "DOE Commercial Rulemaking Issues," March 10, 2003

Charles W. Frazell, PE, "A Preliminary Quantification: The Effects of Excluding Industrial/Manufacturing Sites from the DOE Rulemaking to Determine Efficiency Levels of Unitary Large Equipment," March 19, 2003.

"Comments on the Energy Conservation Program for Consumer Products: Energy Conservation Standards for Commercial Unitary Air Conditioners and Heat Pumps," Docket Number: EE-RM/STD-01-375, as of August 1, 2003, DOE.

Sample BLAST input deck: 1012_DTW_3.ann.blin

DOE presentations and reports from the EERE-Buildings Web site:
http://www.eere.energy.gov/buildings/appliance_standards/commercial/ac_hp.html

Presentations:

- Bryan Berringer, "Introduction," U.S. DOE Workshop on Standards for Commercial Unitary Air Conditioners and Heat Pumps, October 1, 2001, DOE.
- "Commercial Building Energy Use and End Use Load Characterization Analysis," September 2002, DOE.
- Lawrence Berkeley National Laboratory, "Commercial Unitary Air Conditioner and Heat Pump Life Cycle Cost Analysis: Inputs and Results, December 2002.
- TIAX, LLC, "Engineering Analysis: Cost-Efficiency Curves; commercial Unitary Air Cooled Air conditioners and Air Source Heat Pumps, January 2002.

- National Energy Savings Spreadsheet, March 31, 2003 (revised July 25, 2003), DOE
- Life Cycle Cost Analysis Spreadsheet Model (Tariff-Based Electricity Prices), March 31, 2003 (revised July 24, 2003), DOE
- Life Cycle Cost Analysis Spreadsheet Model (Hourly Based Electricity Prices), March 31, 2003 (revised July 24, 2003), DOE

Report:
"Commercial Unitary Air Conditioner and Heat Pump Rulemaking Framework," DOE, June 13, 2001.

Federal Register Notices by Office of Energy Efficiency and Renewable Energy, US Department of Energy:

- Proposed Rule: "Energy Efficiency Program for Commercial and Industrial Equipment: Test Procedures and Efficiency Standards for Commercial Warm Air Furnaces; Efficiency Certification, Compliance, and Enforcement Requirements for Commercial Heating, Air Conditioning and Water Heating Equipment," December 13, 1999.
- "Test Procedures and Efficiency Standards for Commercial Air Conditioners and Heat Pumps," August 9, 2000.
- "Energy Efficiency Program for Commercial and Industrial Equipment: Efficiency Standards for Commercial Heating, Air Conditioning and Water Heating Equipment," March 1, 2000.
- Proposed Rules: "Energy Efficiency Program for Consumer Products: Energy Efficiency Conservation Standards for Commercial Unitary Air Conditioners and Heat Pumps," 10 CFR Part 430, docket EE-RM/STD-01-375, August 17, 2001.