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SYSTEMATICALLY ESTIMATING END-USE ENERGY CONSUMPTION PATTERNS AT LARGE MILITARY INSTALLATIONS*

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ABSTRACT

To help achieve U.S. Department of Defense (DoD) energy-use reduction goals, the Building Use Categorization and Scale-Up (BUCS) system was developed by the Army Corps of Engineers at the United States Army Construction Engineering Research Laboratories (USACERL) in Champaign, Illinois. This article describes the processes by which BUCS systematically groups an installation's buildings into discrete building sets according to their use, usage intensity, age, and size, selects representative buildings from each of these building sets, and then extrapolates the end-use energy consumption patterns of these prototypes (derived from individual building audits or simulations) to the entire facility. It also describes a process which exports the building set and prototype data generated by the system to be used as input to the Facility Energy Decision System (FEDS) for further processing.

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INTRODUCTION

Defense Energy Program Policy Memorandum (DEPPM) 91-2 mandates that all Department of Defense (DoD) facilities reduce energy consumption and costs by 20 percent from 1985 to 2000, and Executive Order 12902 mandates 30 percent by 2005. To achieve these energy-use reduction goals, federal energy managers must be able to determine current energy consumption and costs, assess the energy and economic savings potential of various energy-saving technologies, and budget the economic resources necessary to implement an appropriate energy-use reduction program. To help achieve this goal, the Building Use Categorization and Scale-Up (BUCS) system was developed by the Army Corps of Engineers at the United States Army Construction Engineering Research Laboratories (USACERL) in Champaign, Illinois. BUCS is a software analysis tool that can be used by energy analysts to systematically classify large numbers of buildings into discrete building sets, select the most representative or prototypical building within each of these sets based on derived building characteristic data, and then extrapolate the end-use energy consumption patterns of these prototypes to an entire installation, thus providing an estimate of the facility's overall end-use energy consumption characteristics. BUCS is also capable of producing standardized building set and prototypical building data to be used as input to the Facility Energy Decision System (FEDS)—an important analysis and simulation tool used for analyzing the economic potential of energy efficient technology configurations at federal government facilities.

BUCS ANALYSES

The BUCS system currently assimilates building data from the 1995 Integrated Facilities System Micro-Mini (IFS-M) Army Real Property Database. This database contains the physical characteristics of every building at each U.S. Army installation in the world. For each building, BUCS extracts from this database four attributes: 1) Its general use, 2) its usage intensity, 3) its age, and 4) its area. After these data have been extracted, BUCS groups the buildings in its database into discrete building sets, selects a representative or prototypical building from each of these building sets, extrapolates the end-use energy consumption patterns of these prototypes (derived from individual building audits or simulations) to the entire facility, and then exports the building set and prototype data to be used as input to the FEDS system. These four processes, described in detail below, are referred to, respectively, as binning, prototype selection, scale-up, and FEDS export.

Binning

The purpose of the binning process is to group the buildings of a facility into distinct bins or building sets according to their use, usage intensity, age, and size—criteria that have been shown to be important indicators of the energy consumption behaviors of a given building type [1]. During the binning process, a building is assigned to exactly one of fifteen discrete "bins." These *Level 1* bins include administrative buildings, barracks, dining facilities, family housing units, maintenance/workshop facilities, medical facilities, miscellaneous non-energy-using structures, miscellaneous energy-using structures, production/industrial facilities, recreational facilities, retail facilities, special facilities, training facilities, utility (support services) facilities, and warehouse/storage facilities. These bin categories were derived from a number of sources, including the Red Book [2], the Fort Stewart Integrated Resource Assessment [3], the Non-Residential Buildings Energy Consumption Survey [1], the BOCA National Building Code [4], and the Means Construction Cost Data handbook [5].

After a building has been assigned to a use bin, it is assigned to a *Level 2* bin based on its usage intensity (i.e., the length of time that the building is typically occupied by installation personnel). Examples of usage intensities include 9 A.M. to 5 P.M. Monday through Friday, twenty-four hours/day, seven days/week, and evenings and weekends only. These intensities were derived by carefully evaluating the written descriptions of each of the Level 1 building uses described previously. Figure 1 shows how each of the Level 1 bins is further divided into Level 2 bins.

After a building has been assigned to a use and usage intensity bin, the BUCS system assigns it to a *Level 3* bin based on its year of construction. A military building's age classification is important because the year it is built is oftentimes a good indicator of its construction characteristics and energy consumption patterns. The BUCS system currently separates buildings into five distinct year categories: 1) 1800-1939, 2) 1940-1947, 3) 1948-1970, 4) 1971-1984, and 5) 1985-present. These categories represent a rough description of historical military construction patterns (i.e., the pre-W.W.II era, the W.W.II period, the post-W.W.II building boom, the energy crisis of the 1970s, and the era of present construction methodologies [1]).

Finally, after a building has been assigned to a use, usage intensity, and age bin, it is assigned to a *Level 4* bin based on its total square footage. The system currently subdivides the previous groupings into three building area categories: 1) <5,000 Ft^2, 2) 5,000-30,000 Ft^2, and 3) > 30,000 Ft^2. These bin ranges were derived by attempting to evenly distribute current military structures (by size) between the three bins using a quartile-type division.

An important feature of the BUCS system is that it allows each of the four binning criteria discussed above to be modified, thus permitting the user to change how the buildings are binned or grouped into their associated building sets. Figure 2 provides a summary and example of the BUCS binning process.

- Administrative Buildings
  - → Continuous Use Administrative Buildings, General Use Administrative Buildings, Low Intensity Use Administrative Buildings
- Barracks
  - → Barracks, Intermittent Use Barracks
- Dining Facilities
  - → Retail/Restaurant Facilities, Fast Food Facilities, Institutional Dining Facilities, Lunch Room Facilities
- Family Housing Units
  - → Single Family Units, Multifamily Units
- Maintenance/Workshop Facilities
  - → High Bay Maintenance Shops, Low Bay Maintenance Shops, High Intensity Workshops, Low Intensity Workshops
- Medical Facilities
  - → Dental Clinics, Health Clinics, Hospitals, Laboratories
- Miscellaneous Non-Energy-Using Structures
  - → Non-Energy Miscellaneous, Storage Tanks, Outdoor Recreation
- Miscellaneous Energy-Using Structures
  - → Equipment, Exterior Lighting
- Production/Industrial Facilities
  - → High Intensity, Moderate Intensity, Low Intensity
- Recreational Facilities
  - → Physical Fitness Facilities, Entertainment Facilities, Assembly Facilities
- Retail Facilities
  - → Shops, Offices, Service Facilities
- Special Facilities
  - → Special Facilities
- Training Facilities
  - → Administrative/Classroom, Simulators, General Instruction, Schools, Training Labs (Higher Intensity)
- Utility (Support Services) Facilities
  - → Central Plants, Electronic Communications, Fueling and Pumping Facilities, Service (High Intensity), Service (Low Intensity), Pump House
- Warehouse/Storage Facilities
  - → Bulk (Cold) Storage, Protective Storage, Limited Heating/Cooling (Attendant's Buildings), Warehouses, Storage Shelters, Unmanned Temperature-Controlled Buildings, Administrative/Supply Warehouses, High Bay Warehouses

Figure 1. Level 1 (use) and Level 2 (usage intensity) bins.

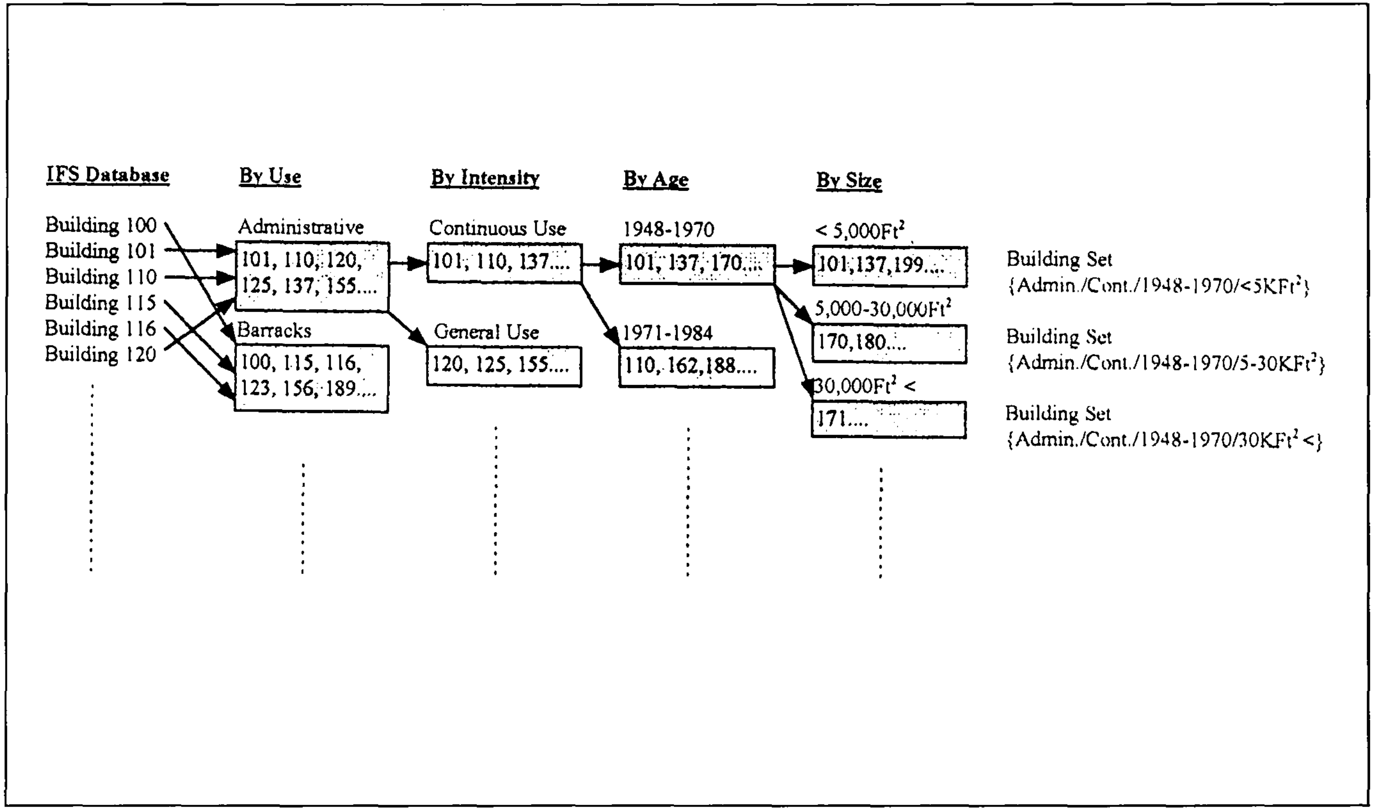

Figure 2. The binning process.

Prototype Selection

The purpose of the prototype selection process is to select prototypical buildings from the building sets created in the binning process. The BUCS system is flexible in that it allows the user to either select prototypical buildings from all of the building sets that have been established or set a series of constraints that limit the building sets from which prototypes will be selected. If, for example, the user is only interested in selecting the most prototypical continuous use administrative building built since 1985 that is between 5,000 Ft^2 and 30,000 Ft^2 in size, he or she would place these constraints on the analysis engine before executing the selection process. The system would then produce for the user the single most prototypical building for the building set that fits that description.

Prototypical buildings can be selected at each of the four bin levels described previously. That is, the user can request Level 1 (use) prototypes, Level 2 (use and usage intensity) prototypes, Level 3 (use, usage intensity, and age) prototypes, or Level 4 (use, usage intensity, age, and size) prototypes. By definition, a Level 1 prototype is the most representative building of all the buildings within its associated Level 1 bin. For example, the building that the system selects as prototypical for all administrative buildings is the single most representative building of *all* administrative buildings at the facility. On the other hand, a Level 2 prototype is the most representative building of all the buildings of a given use (e.g., administrative) and usage intensity (e.g., continuous use administrative buildings), and so forth.

When selecting prototypical buildings, the BUCS system considers both the ages of the buildings at the facility and their areas. However, these two attributes are not always considered of equal importance when determining the most representative building of a given building set. The BUCS system allows the user to modify the relative weights of these two attributes, thus permitting him or her to change their relative importance when determining prototypical buildings. For the army data supplied by the IFS-M database, these relative weights were set at three and one for age and size, respectively. That is, a building's age was considered to be about three times as important as its size when selecting building prototypes. These particular weightings were arrived at by requiring a human expert to select the most prototypical buildings from a series of building sets. The weights were then adjusted by the software engineer until the system was able to reliably emulate the expert's selections. This iterative, test-adjust-test approach to acquiring the human expert's prototype selection expertise proved both effective (i.e., the software's selection algorithm was able to dependably duplicate the expert's selections) and efficient (i.e., only three or four test-adjust-test cycles were required to produce reliable results). Figure 3 shows an example of the output produced by the prototype selection process.

BUCS PROTOTYPES REPORT FOR FORT BRAGG
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Page 1

Prototype # 1

Prototypical Building:	Activation Date:	Bldg Area:
A3048 ADMIN GEN PURP	1941	2794 [Ft2]

Use Bin: Administrative
Intensity Bin: General Use Administrative Buildings
Year Bin: 1940 - 1947
Area Bin: 1 - 4999 [Ft2]
Bldgs in bin: 220
Area:
% in Bin: 22.27
Running Total: 22.27

Prototype # 2

Prototypical Building:	Activation Date:	Bldg Area:
C7417 ADMIN GEN PURP	1987	54692 [Ft2]

Use Bin: Administrative
Intensity Bin: General Use Administrative Buildings
Year Bin: 1985 - 9999
Area Bin: 30000 - 99999999 [Ft2]
Bldgs in bin: 3
Area:
% in Bin: 08.82
Running Total: 31.09

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Figure 3. Example output of the prototype selection process.

Scale-Up

The purpose of the scale-up process is to provide the energy analyst with a systematically derived estimate of how a given facility (or part of a facility) is utilizing its electrical or thermal energy resources. After all prototypical buildings have been selected and have been audited or simulated to determine their respective end-use energy consumption patterns, the scale-up process is initiated. This process takes the consumption patterns of all the audited or simulated prototypical buildings and extrapolates those patterns to their associated building sets. This is accomplished by establishing the total square footage of the building set containing the prototypical structure and then dividing the total square footage of the associated building set by the square footage of the prototype itself. This provides a factor by which each prototypical building's consumption patterns can be multiplied. All of the building sets' energy consumption patterns are then combined, providing an estimate of the facility's overall end-use energy consumption characteristics. Equation (1) shows how the extrapolation process is accomplished.

$$C_F = \sum_{i=l}^{n} \left[C_{Pi} \left(Ft^2{}_{B(P)i} / Ft^2{}_{Pi} \right) \right] \tag{1}$$

where C = consumption pattern, F = facility, P = prototype, and B = building set.

A scale-up of the energy consumption patterns of Level 1 prototypes will produce a very general (and not highly accurate) view of a facility's existing energy use patterns. This is because, for each Level 1 category, a single prototypical building is used in the analysis to represent an entire building type. Thus, only a handful of prototypical buildings (i.e., 15 in the current system) would be used to estimate the end-use energy consumption patterns of an entire facility. The variance produced by a comparison of the attributes of the "most average" building with those of all other administrative buildings at a large facility would tend to be great.

A scale-up of the energy consumption patterns of Level 2 prototypes will produce a more accurate view of a facility's energy use patterns. This is because, at this level, several prototypical buildings are used to represent each Level 1 category. For example, the analysis engine of the system does not select a single prototypical administration building but, instead, selects a prototypical continuous use administrative building, a prototypical general use administrative building, and a prototypical low intensity use administrative building to be used in the scale-up process. Auditing or simulating three distinctly different types of administration buildings provides a much more accurate view of the energy use consumption patterns of the administration building set because, by controlling for usage intensity in addition to use, the within group variance of the Level 2 prototypical buildings is lessened.

Scaling up the energy consumption patterns of Level 3 and 4 prototypes will produce an even more accurate view of a facility's energy use patterns. By selecting, auditing or simulating, and scaling up Level 4 prototypes, for example, the variance of the building attributes within building sets is diminished even further by controlling for the use, usage intensity, age, and size of the buildings. A possible negative of prototyping at these levels, however, is that a potentially large number of buildings must be audited or simulated in order to produce accurate scale up results. BUCS addresses this problem by allowing the user to choose the number of prototypical buildings needed to obtain a relatively accurate base-wide assessment. This is accomplished by displaying the cumulative base coverage of the prototypical buildings. For example, if 90 percent of the entire base can be assessed by auditing or simulating the first thirty-five prototypical buildings, then the analyst may decide that assessing the remaining thirty prototypes would not add appreciably to the data.

In general, a Level 4 BUCS analysis can be expected to produce a reasonably accurate view of a facility's end-use energy consumption performance. Figure 4 shows an example of the output of the scale-up process. The legend window behind the graphic window displays the type of building each segment of the pie represents. By examining the legend in this example, one would see that 29 percent of the total electric energy at this facility is consumed by single family housing units built between 1948 and 1970 that are less than 5,000 Ft^2 in size. In addition, 16 percent of the total electric energy is consumed

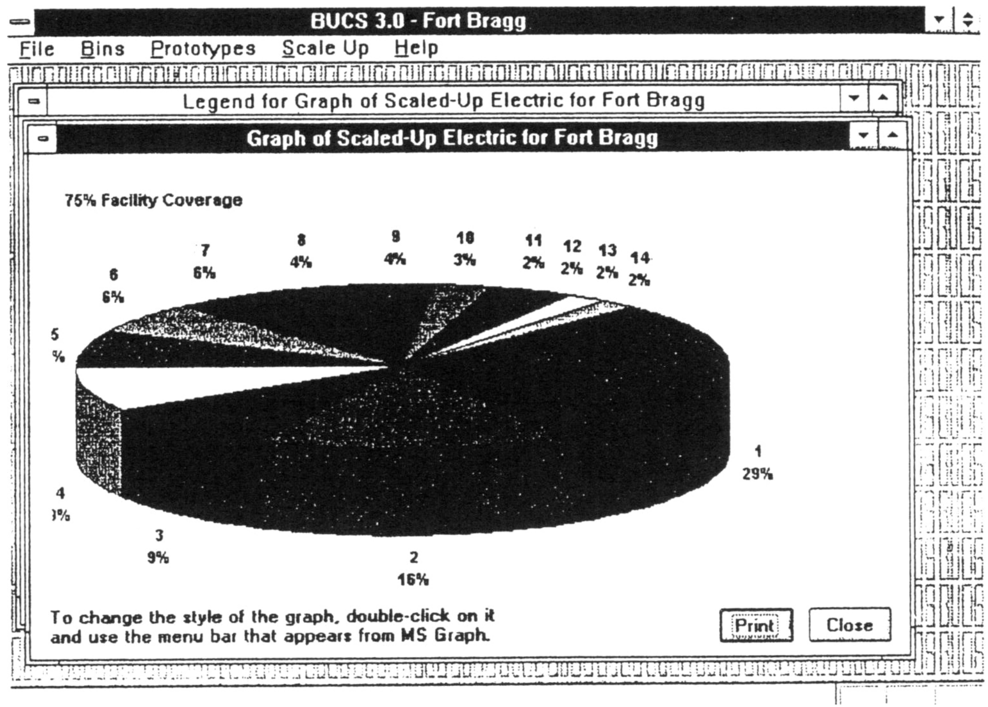

Figure 4. Example output of the scale-up process.

by barracks built between 1971 and 1984 that have an area between 5,000 Ft^2 and 30,000 Ft^2.

FEDS Export

FEDS Overview

The Pacific Northwest Laboratory (PNL) in Richland, Washington has developed a five-step methodology for identifying, evaluating, and implementing cost-effective energy projects at selected federal government facilities [6]. To assist in the automation of a portion of this methodology, PNL has developed the Facility Energy Decision System (FEDS)—a flexible, high-performance analysis and simulation tool, which contains the algorithms and supporting data required for analyzing the economic potential of energy efficient technologies at federal government facilities. More specifically, FEDS assists the analyst in the selection of an energy-saving technology configuration that will decrease the end-use energy consumption at a facility and, at the same time, minimize the total life-cycle cost (LCC) of the retrofit configuration. The software permits the energy analyst to perform fuel-neutral, technology-independent, integrated resource planning and acquisition. FEDS has been used to generate optimal retrofit configurations for entire U.S. Army installations [7-9]. An important feature of the FEDS system is that, when determining the minimal LCC configuration of end-use technologies, interactive effects between the energy systems within and between buildings are explicitly modeled. When considering a compact fluorescent lighting retrofit, for example, the model not only evaluates the change in lighting energy used, but also evaluates any effects the retrofit might have on the current heating and/or cooling configuration. In addition, the software tracks the total facility electrical demand to determine the effect of individual building energy retrofits on the total facility demand peak. This type of optimization modeling takes into account the simultaneous interaction between energy-consuming technologies and is a very effective way of estimating the impact of a comprehensive set of retrofit technologies.

The FEDS system allows the user to input two levels of data—minimal and detailed. To get a quick (and less accurate) analysis, the user need only provide FEDS with a set of very high-level installation information, such as the facility's location, utility rates, building types, areas, etc. A specialized database that contains representative energy-system configuration and construction data is then used to infer those building parameters not explicitly provided by the user. This first pass minimal analysis is typically followed by a more detailed FEDS analysis. In this detailed analysis, the information that was previously inferred by the system is replaced and/or augmented with user-supplied details. The detailed information is gained by selecting prototypical buildings of a given building type and then visually assessing (auditing) or viewing drawings of those buildings to determine more accurately their respective energy-consumption characteristics.

The data obtained is then used to replace as much of the inferred (default) data provided by FEDS as possible. This detailed analysis provides a more optimal retrofit technology configuration and, hence, a lesser LCC of the retrofit package.

BUCS-FEDS Interface

For this process to yield reliable results, the analyst must group the facility building sets well and choose highly representative buildings from each building set. If building sets are not grouped properly, and truly representative buildings are not selected from each of these building sets, the FEDS analysis will not produce reliable results. Thus, it is desirable to group building sets and select building prototypes using a systematic and methodical approach, an approach that is based on an analysis of available building characteristics data. By automating the grouping and selection processes, time savings will be realized and more accurate building groupings and prototype selections will result, especially at very large installations.

After all the buildings of a facility have been grouped into their respective building sets, and a prototypical building has been selected from each, BUCS permits the user to export descriptions of these building sets and prototypes to be used as input to the FEDS program. The export files produced by BUCS can then be opened in FEDS and used together with the additional building data required to perform a FEDS analysis. These additional data include such things as equipment capacities and efficiencies, lighting types and schedules, and utility costs. Figure 5 provides a summary of how BUCS and FEDS interface to produce an optimal, energy-saving retrofit configuration for an Army facility.

SUMMARY

Defense Energy Program Policy Memorandum (DEPPM) 91-2 mandates that all Department of Defense (DoD) facilities reduce energy consumption and costs by 20 percent from 1985 to 2000, and Executive Order 12902 mandates 30 percent by 2005. To achieve these energy-use reduction goals, federal energy managers must be able to determine current energy consumption and costs, assess the energy and economic savings potential of various energy-saving technologies, and budget the economic resources necessary to implement an appropriate energy-use reduction program. To help achieve this goal, the Building Use Categorization and Scale-Up (BUCS) system was developed by the Army Corps of Engineers at the United States Army Construction Engineering Research Laboratories (USACERL) in Champaign, Illinois. The BUCS system currently assimilates building data from the 1995 Integrated Facilities System Micro-Mini (IFS-M) Army Real Property Database. After these data have been assimilated, BUCS: 1) groups the buildings in its database into discrete building sets according to their use, usage intensity, age, and size; 2) selects a representative or prototypical building from each of these building sets; and 3) extrapolates the

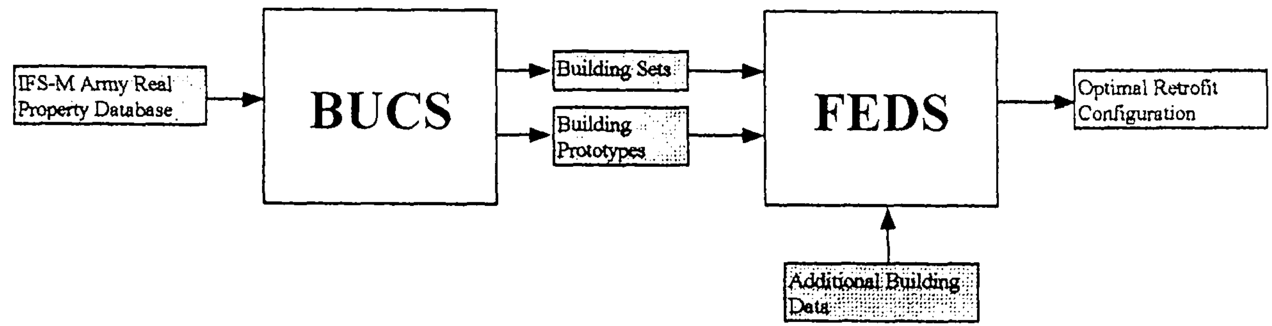

Figure 5. BUCS conversion of IFS-M data into building sets and prototypes for use as input to FEDS.

end-use energy consumption patterns of these prototypes (derived from individual building audits or simulations) to the entire facility, thus providing the energy analyst with a systematically derived estimate of how the facility (or part of the facility) is utilizing its electrical or thermal energy resources. In addition, BUCS is capable of exporting its building set and prototype data for use as input to the FEDS system—an analysis and simulation tool used for analyzing the economic potential of energy efficient technology configurations at federal government facilities.

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