COMPUTERIZED BUILDING SIMULATION... *A DSM STRATEGY?*

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ABSTRACT

This paper explores the importance of computerized building simulation as a strategy for effectively attacking heating, ventilating and air conditioning (HVAC) and other complex energy efficiency opportunities in buildings, and the present low level of expertise in its use in the industry. HVAC will be the "nut" that is hard to crack in DSM programs. Because of this, superior investigative and analytical practices will need to be more broadly and correctly employed to reach long-term DSM goals. A case study is presented showing both the mis-use and correct use of computerized building simulation in a building energy retrofit program. Guidelines for proper performance of computerized building simulation are presented. Two additional case studies are presented showing possible cost-effective methods of utilizing computerized building simulation. Finally, recommendations for employment of computerized building simulation are presented.

INTRODUCTION

"Energy conservation" was the watchword of the energy crisis of the late 1970's and early 1980's. It would seem that "Demand Side Management" has become the watchword of our current love affair with energy efficiency. Our lawmakers and public utilities commissions (apparently out of concern for the environment, global economic competitiveness, and national security vis-a-vis dependence on foreign oil) have re-discovered in recent years that a kilowatt of power or a kilowatt-hour of energy can be "created" through energy efficiency at a much lower economic and societal cost than by building a power plant to produce it. As a result, utility companies across the nation are "under the gun" to create and implement Demand Side Management programs and the nation is a-buzz with Demand Side Management Conferences, newly-formed professional associations, and utility-sponsored Demand Side Management programs. As practicing energy engineers well realize, there is very little new under the sun in terms of energy efficiency technology. What is new is the enthusiastic support of energy efficiency by the utilities and their head-long rush to implement energy efficiency programs under the banner of "Demand Side Management".

While the utilities, and the various public utilities commissions, tend to take rather global points of view relative to the implementation of such programs, the core of any building energy efficiency improvement program has always been, and will always remain, a matter of product technology and engineering application. Unfortunately, the rush to implement global programs frequently has attendant to it a tendency on the part of the bureaucrats and program managers towards over-simplification of the problems at hand as well as a tendency to treat the fixes as commodities - rather like many large, top-down programs. Indeed, it is actually a bit frightening that one of the national demand side management associations recently displayed compact fluorescent lamps on their annual meeting brochure as if to say this one technology is all there is to demand side management! In addition, demand side management RFP's may state that "cream skimming" is a phenomenon that the RFP "has been designed to avoid"... yet the criteria for selection built into the RFP results in the selection of proposers, who concentrate on a single technology, generally lighting. Certainly, there are many technologies, such as compact fluorescent lamps, which clearly do not require "rocket science" for their employment. However, the achievement of systemic energy efficiency in our society is going to take much more than the "cream skimming" which is current practice.

The nations largest investor-owned utility company has set a 2,500 megawatt customer energy efficiency goal by the turn of the century. Virtually all of the anticipated load growth in their service area is intended to be met by their demand side management programs. Early success in demand side management programs is a virtual certainty, given the ennui that, in truth, has always met energy conservation, leaving "rafts" of inefficient buildings and building systems throughout our society. As a result, cream-skimming the simple and "no-brain" energy retrofits (such as lighting) in these buildings will produce dramatic early results. However, once this largely untapped reservoir dries up, the "fun" will begin. Indeed, roughly one-third of the 2,500 megawatt goal mentioned above is intended to come from heating, ventilating and air conditioning (HVAC) system improvements. It will take more than a "screw-in" technology to tackle these "tough nut" energy efficiency opportunities, yet the demand side management industry and profession is poorly prepared to do so.

Unfortunately wholesale order-of-magnitude increases in the level of energy conservation investment can only be accomplished, and is apparently being accomplished, by a wholesale creation, virtually from scratch, of a whole new cadre of energy auditors and project implementors as well as new auditing and project implementation techniques and procedures. Unfortunately this forcing the rate of energy conservation market penetration has largely not made use of the value of the experience and expertise of the energy engineering cadre that "paid their dues" during the energy crisis of the 70's and early 80's (the people who were serious about energy conservation during our nation's energy crisis and who, by-and-large did not work for utility companies - as the utility company energy conservation programs of that period were more proforma than substantive). As we enter the 90's we find that those who are probably not the best qualified are in possession of the "keys" to the energy conservation "kingdom". The result, and it is already well underway, has been the creation of a new highly theoretical and highly academic energy conservation industry which may produce more "paper" demand and energy savings than actual demand and energy savings.

To achieve persistent, long-term energy efficiencies will require employing numerous sophisticated hardware and analytical technologies carefully developed and refined over the years by energy engineering professionals. In support of this notion, the purpose of this paper is to explore, principally by means of three case studies, an analytical technology which we suggest, is of such import to demand side management, that it should adopted by the industry not just as a tactic but as a fundamental strategy that will allow the industry to achieve its full potential. That technology is generally known as computerized building simulation.

COMPUTERIZED BUILDING SIMULATION

Starting in the mid-seventies, computer simulation of buildings was developed as a practical tool for the engineering of buildings. The tool has found significant use during the design phase of a building to develop load estimates and optimal combinations of building features. The tool has perhaps found even better use in the analysis of existing buildings for energy conservation retrofit. By simulating retrofit options on the computer, reliable estimates of potential energy savings may be achieved, assuming that the initial modeling and subsequent modeling of retrofit measures has been well done. In its essence, computerized building simulation is no different than an accounting balance sheet for a business. As it is generally practiced, computerized building simulation includes the following steps:

- field survey of the facility
- review of as-built drawings
- construction of the model, including describing the building and its energy-using systems to the computer
- running the model and comparison of the modeled energy use to actual energy use data
- simulation of energy retrofit modifications
- determination of energy savings by comparison of baseline and retrofit building models

The principal benefits this technology brings to the table are as follows:

- An accurate energy balance of all the sources and uses of energy in a building is an integral part of building simulation. By properly assigning energy consumption to end uses, estimates of end use savings is dramatically improved.

- When considering multiple energy retrofit measures, building simulation is the only technique which can accurately and completely account for the interaction between measures to avoid "double counting" of savings and provide good estimates of secondary effects (such as reduced air conditioning from reduced lighting loads).

- The effects of changes in a building's size, occupancy, or hours of use following retrofit can only be properly be accounted for by re-modeling the pre-retrofit building to create a new "pre-retrofit" baseline for comparison with post-retrofit energy use of the changed building.

While the use of computerized simulation somewhat "automates" the process of generating estimates of energy savings, the true value lies in the quality and accuracy inherent in the process, not its potential for labor reduction.

As discussed above, State Legislatures, Public Utilities Commissions, and utility company's are pushing demand side management as a less costly and environmentally superior alternative to building power plants. The "kicker" in this formula is the demand for "accountability" in the process, i.e., payment based on performance. This results in a greatly increased scrutiny of energy savings projections and post-retrofit verification of savings - with dramatic financial implications for the utility company if the results are unsatisfactory. In addition, the current economic climate has brought renewed emphasis by building owners on controlling operating costs through energy retrofit. Added to this is the fact that as more and more of the more straightforward energy retrofit work is performed (such as lighting, high efficiency motors, etc.) the market for energy conservation must shift to the more difficult energy retrofits, such as HVAC system and control system modifications - which do not readily lend themselves to simplistic analysis.

The result of this evolution of the demands of the energy retrofit marketplace is that energy engineers, contractors, building owners, government, and utility company employee's must find more accurate ways to predict the future energy savings performance of energy retrofit work. The technology rapidly being employed to meet this challenge is that of computerized building simulation.

While emerging as the "technology of choice" for energy retrofit engineers, computerized building simulation suffers from a number of problems at the present time. These include:

- Most of the building simulation programs that exist were created to address the question of new construction, not retrofit! As a result these programs have many gaps and weaknesses which must be overcome by their users when employed in the evaluation of energy retrofit.

- The only instruction generally available on computer simulation of buildings is provided by the vendors of individual computer programs. Unfortunately, their instructions generally is limited to the use of their program, not the overall process of building simulation and its quality control. As a result, this instruction tends to be very "academic" in nature, and therefore incompletely effective.

- Existing common practice and tradition tends to treat building simulation programs as "black boxes" with an attendant unwarranted "blind faith" in the validity of the computer generated program output (at least one expert in the field refers to this phenomenon as "printout perfect"). As a result, practices and procedures to ensure accuracy in the modeling process have not generally been recognized as needed nor have they become widely used. In addition, "crafty" practitioners can "fake" building simulations fairly effectively, taking advantage of this "blind faith" phenomenon.

To illustrate the above points, a series of case studies are presented in the following. Each depicts a different aspect of the use of computerized building simulation as an important tool in demand side management programs.

CASE STUDY #1... *THE THRILL OF VICTORY... THE AGONY OF DEFEAT*

The Situation.

A local County performed a large energy retrofit project on their large civic center building which housed the majority of the county administrative offices, and the county jail. This project was implemented in a design/build fashion, with the installing contractor (a large and very reputable design/build and controls company) performing the feasibility study and preparing the needed rebate documentation. After nearly a year of negotiations, the utility company, the county and the contractor could not come to terms on a final savings and rebate figure. While the utility had serious reservations about the computer simulation used to generate the estimate of energy savings, it was unable to pinpoint specific flaws in the modeling work. The situation was at an impasse.

Our firm was engaged by the utility company to review the rebate application and supporting documentation for the energy retrofit project (already installed) and arrive at a supportable number for the estimate of energy savings. The completion of this task required the following to be done:

- review of the rebate documentation as presented by the owner and prepared by their design-build contractor
- review of pertinent project documents in the possession of the owner or their design-build contractor
- interviews with owner's and design build contractor's personnel
- an on-site observational survey of the building, its HVAC systems and the energy retrofit work performed
- computerized analysis and review of utility consumption data for the two years prior to and the year following completion of the retrofit project
- detailed analysis of the rebate application and its documentation to identify possible inaccuracies therein
- recalculation of the energy savings by means of an approved building simulation program
- preparation of a final report of the results of the work

Summary of the Findings of the Investigation.

The following are a summary of the findings of the investigation and analysis:

1. The energy retrofit project was well conceived and implemented. The project attacked fundamental inefficiencies inherent in the buildings' design, rectified those inefficiencies and is saving considerable energy. It was and is a good investment on the part of the owner.

2. The project could have easily been more extensive in nature - there were numerous additional inefficiencies that could also have been corrected (lighting controls, lighting fixture retrofit, variable flow chilled water, variable flow cooling tower fans, and variable speed drives for multi-zone unit fans).

3. The original estimate of energy savings was optimistic. Revised calculations indicate that about 50% of the original estimate was reasonable. In addition, the building was actually saving about 50% of the original estimate, as evidenced by the utility invoices themselves.

Description of the Facility.

The County Civic Center consists of two adjoined buildings, the Administration Building, which was built first, and the larger Hall of Justice which was constructed at a later date, together totalling approximately 370,000 square feet. Both of these buildings are multiple story (nominally 3 to 4 stories - of a very non-traditional nature due to the unique architecture employed) and are very long and narrow with their major axis running generally in a north-south direction. The buildings are constructed of reinforced concrete with the exterior skin principally consisting of glass curtain walls and precast concrete panels. In addition, the buildings are bisected along their major axis with a public mall which is open to ambient air and is essentially an unconditioned space. Lighting is mostly fluorescent and has received some minor energy conservation retrofits over the years, but is devoid of switching controls in the occupied space (lights must be switched on and off from electrical panels).

The buildings are heated and cooled by 26 primary air handling systems, virtually all of which are double-duct or multi-zone in nature. All the systems are equipped with outside air economizers and are provided with cooling from a multi-chiller central cooling plant and with heating from a multi-boiler central heating plant.

Special areas such as computer rooms are equipped with small self-contained air conditioning systems.

Prior to the energy retrofit project the building's primary HVAC systems were scheduled on and off by a rudimentary building automation system. In addition a few select areas, including the County Jail, the Sheriffs Department, the lower lobby/patrol area and the computer room stay in continuous operation at all times.

Description of the Retrofit Work.

The retrofit project was primarily focused on the HVAC and building automation/temperature control system and consisted primarily of:

- retrofitting 13 double-duct air handling units in the Hall of Justice to variable air volume with variable frequency drives on the supply fans and direct digital controls on the air handling units, along with direct digital controls and variable volume conversion of the double duct mixing boxes - with the exception of the Sheriffs Department, the 24-hour operation systems were not retrofitted in the Hall of Justice

- in the Administration Building all 10 multi-zone air handling units were converted to variable air volume by means of replacing their multi-zone damper sections with damper sections having separate actuators for the hot and cold dampers for each zone - these air handling units also received direct digital controls, but did not receive variable frequency drives

- the operation of both the building boilers and the chillers were also automated as part of the building automation system installation

The engineering principles inherent in the retrofit work which could be expected to give rise to energy savings are the following:

- both double-duct and multi-zone HVAC systems, by their very natures, mix heating and cooling constantly in order to achieve the desired space temperature - conversion to variable volume eliminates all or nearly all of the mixing of heating and cooling

- outside air economizers on mixing systems give rise to very high levels of heating energy use (as all the cold mixed air that goes down the hot deck must be heated to the hot deck setpoint temperature) or, as was the case with the existing temperature controls in this building, the outside air economizers must be "locked out" in colder weather - conversion to variable air volume allows for greatly improved coordination of the use of the outside air economizer in support of cooling operations, without increasing the energy used for heating

- multi-zone and double-duct HVAC systems are constant volume systems which provide a constant volume of air delivery to the occupied space regardless of the actual magnitude of the need for heating or cooling in the occupied space - conversion to variable volume when combined with fan speed control can dramatically decrease the energy used for air circulation, especially when airflows have been over-designed - where variable speed fan drives are not used, fan savings can also be achieved by means of reducing the fan's airflow output by means of dampers, though fan savings will be minimal if this retrofit simultaneously employs supply air reset (as was the case here)

- the reduction of end-use cooling and heating is reflected in the cooling and heating plants in the form of reduced load and/or reduced hours of operation of the primary cooling and heating equipment (chillers and boilers) - in addition this also has a secondary, and somewhat minor effect of reducing the energy used by pumps, cooling tower fans and other plant auxiliaries

As learned through the field survey and interviews, the intent of the project was very well implemented. All of the equipment necessary to achieve the project's energy saving objectives was installed and made operational (this is not always the case in projects of this sort). In addition, the quality of the work performed was of the highest caliber - better than any of the many other projects we have reviewed. The equipment worked and the operating engineers appeared to be comfortable using the building automation system.

Review and Analysis of Energy Use Data.

As documented in detail in the final report, a computerized review of approximately 4 year's worth of utility consumption data was performed. The data led to a number of interesting observations and/or conclusions, as follows:

- Since installing the energy retrofit project the long term trends in electric and gas consumption were both <u>down</u> (see Figure 1).

- During calendar year 1992 the building used 990,621 <u>fewer</u> kilowatt-hours of electricity and 74,695 <u>fewer</u> therms of gas than the "base" year prior to implementation of the project (calendar year 1990).

- Utility cost avoidance during calendar year 1992 totalled more than $125,000, compared to the base year.

- While overall energy use had been reduced by approximately 20%, the combined average unit cost of electric and gas had increased by approximately 25%, resulting in a total energy bill virtually identical to that prior to the implementation of the project. This was an important consideration for the owner and why the term "cost avoidance" was used above. Had the project <u>not</u> been implemented, the owner's total cost of utilities for 1992 would have been $125,000 greater than it actually was. Hence, cost was <u>avoided</u>, even though the cost in 1992 was the same as 1990.

As also documented in the final report, the 30-minute demand records for the building were also reviewed and analyzed. While analysis of this sort requires careful interpretation is not so apparent as the utility consumption records discussed above, the analysis of graphs of the electrical demand revealed the following:

- the hours of operation of the buildings' HVAC systems had been slightly reduced (roughly one hour per day), resulting in reduced energy use, and consistent with the retrofit work installed

- HVAC systems that were left to run 24 hours per day during extreme cold or hot weather in the past appeared to now be automatically controlled to avoid this condition - resulting in reduced energy use, and consistent with the retrofit work installed

- peak electrical demand was being reduced in all seasons of the year except the summer months - resulting in reduced energy use, and consistent with the retrofit work installed

- the building lighting was being turned on earlier and off later than in the past - resulting in increased energy use, and possibly "masking" some of the energy savings being achieved by the retrofit project

Finally, the above calculation of avoided cost not only did not take into account the effect of the added lighting consumption mentioned above, but it also did not consider the added energy used by small computer-room air conditioning units installed since the retrofit project was completed. It also did not reflect the savings being achieved by shutting down personal computers at night and on weekends, which had been initiated just prior to ERA's investigation (based on February '93 demand records, this was worth about $50,000 per year if it could be sustained!).

Review of the Rebate Application Savings Estimate and Original Building Model.

As a part of the task, the supporting documentation for the rebate application was reviewed and critiqued. As is somewhat common practice when computerized building simulation has been used for documenting the rebate application, the estimate of energy savings was generated by contrasting computer models of the building as it existed prior to retrofit and as it was intended to exist following retrofit. The majority of the critique comments are therefore focused on the modeling process.

The following were the aspects of the energy savings analysis which were found to be less than appropriately rigorous for a project of this magnitude:

- The model of the existing (and retrofitted) building was overly simplistic in that areas and HVAC systems of greatly different character (e.g., 24 hour operation versus 12 hour per day operation and different type HVAC) were "lumped" together (the entire building was modeled with three HVAC systems), thereby over estimating the energy used by HVAC systems that were intended to be retrofitted.

- Due to the above, electrical energy used for "process" purposes (such as centralized computers) was also "lumped" in with regular office space, thereby over estimating the energy used by HVAC systems that were intended to be retrofitted.

- In the model of the existing (and retrofitted) building, certain HVAC systems were modeled as different "types" than they actually were (for example, double-duct systems were modeled as terminal reheat systems, which function in a very different fashion).

- In the model of the retrofitted building, incorrect equipment was modeled, specifically variable frequency fan drives were modeled on the Administration Building HVAC, while no drives were planned for or installed on these systems.

- Certain HVAC parameters were specified in the retrofit model which were very optimistic. Specifically:
  - most fan efficiencies were increased (even though no fan modifications were planned or implemented)
  - "design" static pressures for supply fans were greatly reduced on double-duct systems (even though only minor static-pressure-reducing changes to the supply air distribution system were planned and implemented)
  - "design" static pressures on double-duct return fans were reduced (even though no changes to the return air distribution system were planned or implemented)
  - "design" static pressures for supply fans were greatly reduced on multi-zone systems (even though no static-pressure-reducing changes to the supply air distribution system were planned and implemented)

Figures 2 through 4 provide graphic analysis of the existing building model submitted with the rebate application. This model did successfully calculate a total annual energy use for the building which agreed quite well with the building's actual annual energy use. However, from observation of these graphs, it can be seen that the model is not a faithful representation of the building as it existed prior to retrofit. Specifically:

- the seasonal patterns of electric and gas use do not match up well between actual use and the model (note that the modeled electrical consumption is very much more seasonal than the actual consumption and that the modeled gas consumption peaks in the summer rather than winter months!)

- the daily pattern of electrical use does not match up well between the actual use and the model - weekdays and weekends both do not match (note that middle of the night loads are essentially missing in the model as the computer room and other 24-hour loads were "lumped" in with single-shift office operations)

The above comments, as simple as this author may make them sound after performing rigorous examination of the documents, might seem to infer poor intent on the part of the design-build contractor. However, they are really more indicative of the general lack of understanding of the fairly high level of expertise and skill needed to perform truly accurate computer modeling of complex facilities, and the lack of accepted quality control practices in the industry for this type of work (the data to perform the above critique must be "wrestled" from the most building simulation programs).

Revision of the Rebate Application Savings Estimate and Building Model.

In keeping with the project's goal of not re-doing entirely the rebate calculations (though in hindsight it might have been easier to do so), the same computer modeling program was used to re-model the existing building and re-model the retrofitted building.

While the process was ultimately successful, the CEC-certified program that was used has been significantly improved since it's original dependence on "bin" weather data, it still has a number of drawbacks that probably make it a poor choice for retrofit work, in spite of it's CEC "imprimatur." Specifically:

- the program lacks many types of HVAC systems, including double-duct and variable-volume-double-duct (the majority of the building was/is served by such systems)

- the program lacks the ability to model supply air reset except on re-heat systems - virtually all existing buildings are equipped with some sort of supply air reset - as was the Civic Center - this feature is extremely valuable for modeling existing buildings

- the program is somewhat of a "black box" in that it "hides" certain information from the user deep within itself, such as the kw of the fan and pump motors which the program is using for modeling (the original model, for example was estimating fan kw at approximately twice what is actually installed in the building)

- control over cooling plant auxiliaries such as pumps and cooling towers is poor to non-existent (peak pump kw can be "backed into", but not controlled, and cooling towers are completely inaccessible to the program user)

- only one place is available for describing to the program the numerous non-HVAC electrical uses (such as exterior lighting, exhaust fans, domestic water pumps, etc.)

- the program documentation leaves a lot to the imagination, requiring that the effects of certain features must be determined by experimentation with the program, and is therefore very time-consuming

Nevertheless, an accurate model of the existing building prior to retrofit was created with the program and graphical analysis thereof is presented in Figures 5 through 9. Readers will note that the revised model follows both seasonal and daily energy use patterns quite closely. In addition the model agrees with actual annual electric use within 1% and gas use within 5%. This was achieved by modeling the building in more detail (7 HVAC systems were modeled in lieu of the original 3) and through an iterative "calibration" process consisting of a careful critique of the model output, revision of the input, and re-running the program until achieving a faithful model of the building - or at least as faithful a model as was possible within the capabilities of the program. This re-modeling process consumed approximately 3 person-days of effort, which was significant because the author had nor used this particular computer program previously.

Once a good model of the existing building prior to retrofit was completed, this model was then used to simulate the effects of the retrofit work.

Finally, the output of both models was analyzed and the savings predicted by the model summarized in a spreadsheet that appears as Table 1. Overall, we considered this estimate of savings to be conservative, because:

- the retrofit model was unable to include savings from reduced HVAC operating hours in extreme weather

- the "accommodations" made in the model to achieve a faithful seasonal energy use "match" resulted in the elimination of significant mixing of heating and cooling in the early hours of the day during summer months - which would have been saved in the retrofit computer model (this "accommodation" was necessary due to the lack of supply air reset capability in the computer program - see the weekday summer demand graph comparing the revised model to actual for "missing" electrical use early in the day).

Case Study #1 Conclusion.

As supported and suggested by the foregoing, the following conclusions and/or recommendations were made to the utility company:

- even though the original estimate of energy savings was optimistic, the retrofit project was essentially well conceived and implemented and should be considered a success by the owner, both because substantial tangible costs are being avoided and many other benefits are accruing to the owner in terms of reduced maintenance and replacement costs for previously failing controls, improved comfort (in all likelihood) and much greater ease of building operations (probably freeing up operating engineers to perform other tasks, previously left undone or done by others).

- further opportunities for increased efficiency of building operation exist and should be pursued by the owner and the utility company at their mutual earliest convenience

- a rebate payment on this project based upon the savings figures presented in the report was justified, both because the revised estimate was realistic and was supported by the analysis, but also because this level of savings was actually being achieved by the equipment installed in the building - subsequent "disallowance" by PUC auditors should not be a problem

- the creation of realistic and workable standards for the use of computer simulation for rebate calculations might be a worthwhile endeavor for the utility company to undertake

In addition, this particular case study made it poignantly apparent that things were not right in the profession of computerized building simulation, and that changes needed to be made in the practice of the profession if this valuable technology were to continue in use and fulfill its destined role in the business of demand side management.

AVOIDING THE PITFALLS

While the case study above might seem the rare case, as observed by the author in the process of auditing and reviewing energy savings calculations and building simulation work performed by reputable and experienced professionals in the field (both as an expert witness for building owners and as a quality control consultant for a large utility company), the improper use of computerized building simulation has resulted in the frequent inaccurate estimation of savings for energy retrofit projects, to the embarrassment and consternation (and occasional financial downfall) of the parties involved in major retrofit projects.

Unfortunately, the common use of computer modeling for Title-24 certification of new buildings (in California), for example, has really led the public and a large part of the HVAC profession "down the garden path" on this subject. While the State of California, and others, might be comforted by resting their faith in a "California Energy Commission (CEC)-certified" computer program, the truth is that veracity in computer modeling of existing buildings lies only in the hands of the professional performing the work. Unfortunately there are very few professionals competent in the field of modeling existing buildings, though many may mistakenly think they are competent or have a wealth of experience in modeling new buildings (which is largely an academic endeavor).

This situation is unnecessary as the author has used a wide range of computer simulation tools over the past 10+ years to prepare savings estimates for a large number of comprehensive energy retrofits in both large (1.8 million square feet) and small (25,000 square feet) buildings with great success. However, this success has been achieved through the development and rigorous employment of a set of quality-control practices developed over many years. These include:

- the development of **intimate knowledge of the simulation program** to be used, including its various idiosyncracies and nuances, involving detailed understanding of:
  - how the input data is understood and utilized by the program
  - the calculations/algorithms employed by the program
  - the flow of input and calculated values through the program
  - the precise effect various program "controls" exert on the calculations performed by the program

  (The bottom line here is that an inferior simulation tool in the hands of an engineer well versed in its features and capabilities is superior to the best simulation tool in the hands of an engineer unfamiliar with it.)

- **an intimate understanding of the building being simulated,** vis-a-vie its physical and operational characteristics - in essence, in existing buildings, the quality of the survey or "audit" determines the quality of the simulation - this is particularly true in complex facilities and is accomplished by:
  - conducting an observational survey, generally ,including careful observation of the functioning of the building's temperature control systems, sample measurement of system operating parameters (supply air temperature, mixed air temperature, space discharge air temperature, etc.) as a means of observing the actual performance of the control system, a "late night" tour of the facility and its HVAC systems to identify actual HVAC operating schedules, control system performance, and lighting system schedules (which are frequently under the control of the custodial crew)
  - conducting an electrical load survey, including (for large buildings) the measuring the instantaneous power draw (volts, amps and power factor) of every electrical panel and piece of equipment (even in small buildings, the connected loads of major pieces of equipment can be quickly measured), the recording of power demand over time for large and fluctuating loads (chillers and the like) - in addition, the utility company frequently records the building's power demand over time (utilizing magnetic tape or bubble memory meters) and the information from these meters is almost always available from the utility company (and this data can be used to confirm building operating schedules and for comparison of hourly profiles with the model of the existing building)

  (This is perhaps the single most important factor in developing accurate computer models of existing buildings, and where most "academically"-oriented practitioners go astray.)

- careful **analysis and critique of output data** (again, just because it is carefully prepared and computer generated doesn't mean it is correct), including:

  - an annual energy-use profile comparison, which is a gross, year-long evaluation of the modeled energy use in comparison to actual energy use - while the annual totals may agree, seasonal variations may not agree well with each other, indicating that weather-influenced systems are not modeled well - graphic comparison of modeled and actual energy use is most valuable in this evaluation, as was seen in the case study above - in addition comparison of the actual and model weather data can also be valuable

  - peak load comparison wherein the peak modeled loads are compared against known values such as the utility company's data for the building's peak electrical demand for all seasons of the year - similarly, the building's peak cooling load is probably known from operating engineers' observations and/or operating logs, and this too, can be used as a scale of measure for evaluating the accuracy of the computer model, by comparing actual peak cooling loads from days having peak temperatures similar to the peak temperatures in the simulation program's weather data file

  - detailed output analysis of retrofit models, wherein only the functional energy use of the system being retrofitted is examined to compare the original and retrofit consumption for correct simulation and plausibility (amazingly, due to a simple keystroke error the lighting energy can be reduced by a variable volume retrofit or a variable volume retrofit can reduce fan energy consumption by 95% - and these errors would be "hidden" within the building's total energy consumption and not be caught without this simple check)

  (This step is the one that is perhaps the hardest to do because it is counter to the intuitive desire to believe that the work has been done correctly and the desire to keep the project moving forward.)

- **conducting an overall plausibility check** by summing all the savings for all retrofits, a gross plausibility check can be performed by applying engineering judgement regarding whole building energy-use levels that are reasonable for the type of building being evaluated - while this is a gross measure, even such a simple check can be effective in catching unreasonable optimism in energy savings estimates that may have slipped through all the other quality control measures

If it is not already obvious, virtually all of the "quality control" techniques mentioned above were utilized in the review and correction of the computerized building simulation described in the case study above. Furthermore, by utilizing the above techniques, we have found it possible to regularly model buildings within 5% of their actual annual energy use with a high degree of confidence in the simulation of each energy-using system and functional use of energy in the building.

The case study above, and much of the recommendations presented herein apply to larger and more complex buildings and assume both a fairly extensive modeling labor effort and a complex modeling program. However, the effective use of computerized building simulation is not at all limited to these regimes, as the following brief case studies will demonstrate.

CASE STUDY #2... *"BUT ISN'T COMPUTERIZED BUILDING SIMULATION TOO TIME-CONSUMING TO BE COST EFFECTIVE?"*

The common assumption is that computerized building simulation is extremely time-consuming and expensive. While the use of the DOE-2 or TRACE (or other mainframe computer origin program) computer programs may be justified for use in the examination of a large or very complex building, they are indeed labor intensive and time-consuming programs to run (even on very fast personal computers, runs times on complex buildings frequently runs into hours in duration). However, alternatives exist for making quite sophisticated computerized models of buildings in rather short time periods.

This case study involves an office/R&D/manufacturing facility in the Silicon Valley. The building was approximately 84,000 square feet in size and was equipped with primarily packaged rooftop air conditioning/heating units (though one small chiller/air handler system was also employed).

A field survey was conducted by a service contractor's technician who identified the principal hours of occupancy, lighting use and HVAC system operation, provided an HVAC equipment list, and provided a thumbnail sketch of the various activities in the building. In addition, a utility company 12 account summary was provided, showing the previous 12 month's gas and electric consumption.

The purpose of the effort was to provide the building owner with a reasonably good, but low cost estimate of the probable savings that would accrue from the installation of and energy management system to control both HVAC and lighting systems.

Using ERA's proprietary, spreadsheet-based ©*BEST* building simulation program, a model of the building was created with the results shown in Figures 10 and 11, which show the results from <u>the very first simulation run</u>. As can be seen from the figures, the seasonal correlation of both electrical and natural gas consumption was excellent. IN addition, the model agreed within 10% and 1% with the actual electric and gas consumption, respectively.

Once the existing model was thus built and verified, the two energy retrofit measures were each also simulated, a summary of savings spreadsheet prepared and a brief report prepared, including approximately 4 pages of original text and approximately 45 pages of supporting documentation, ready for printing and binding.

From start to finish, the tasks described above consumed a grand total of 5 labor hours to complete, making it clear that an accurate and meaningful computerized building simulation does not have to be prohibitively time-consuming nor expensive.

CASE STUDY #3... *"A SIMULATION CAN'T BE ACCURATE WITHOUT HOURLY HEATING AND COOLING LOAD CALCULATIONS... CAN IT?"*

Another common assumption in the industry is that a building simulation cannot be accurate unless it performs hourly (some would press for half-hourly!) heating and cooling load calculations employing ASHRAE calculational methodologies. The purpose of this third case study is to demonstrate that very meaningful and <u>valuable</u> results can be achieved by using a simulation methodology which does <u>not</u> employ thermal heat gain and loss calculations for building heating and cooling system operation.

This case study involves an office building which was one building of a three building complex in the southern portion of the San Francisco peninsula. The building was approximately 31,000 square feet in size and was equipped with a single built-up HVAC system of double-duct configuration with direct expansion cooling and hot water heating.

A full feasibility study was conducted including a thorough field survey and a goodly number of field measurements, observations of HVAC system operation and monitoring of whole-building electrical demand for a short period during the survey phase. In addition, the owner's gas and electric utility invoices were analyzed for the three years prior to the study.

The purpose of the feasibility study was to develop a comprehensive HVAC system retrofit that would reduce energy use and cost and improve building comfort and operations. While lighting was considered, it was intentionally requested by the owner to not be a focus of the study.

Using ERA's proprietary, spreadsheet-based ©*BEST* building simulation program, a model of the building was created with the results shown in Figures 12 and 13. As can be seen from the figures, the seasonal correlation of both electrical and natural gas consumption was excellent. In addition, the modeled electric consumption agreed within 3% of the actual, and the modeled gas consumption agreed within 6% of the actual.

Once the existing model was built and verified, a variety of HVAC retrofits were simulated and documented in the final report. The owner of the complex ultimately implemented comprehensive HVAC retrofits in all three buildings. These projects were implemented on a design/build basis and included direct digital controls, conversion to variable volume including variable frequency drive installation and conversion of all boxes to pneumatically-controlled double-duct/variable volume operation, and re-commissioning of the defunct outside air economizers.

Subsequent to the completion of the projects, the performance of the projects was evaluated using direct utility bill comparison. The case study building produced 103% of its projected savings, while the complex overall produced and average of 93% of the projected savings, performance which the owner found to be very satisfactory.

CONCLUSIONS AND RECOMMENDATIONS

As hopefully has been demonstrated in the foregoing, "messy" energy retrofit measures such as those pertaining to variable load HVAC systems and equipment can be most accurately analyzed through the use of computerized building simulation. In addition, the use of computerized building simulation does not have to be prohibitively expense and therefore limited only to very large and very complex projects. If more simplistic methodologies are employed, in conjunction with appropriate quality control measures, even relatively modest projects can, and should, be analyzed through the use of computerized building simulation.

Agencies, such as utility companies should accept, and perhaps demand, computerized building simulation be employed in their programs. Before doing so, however, they should seriously consider the creation of realistic and workable standards for the use of computer simulation for savings calculations. While it is the most accurate and honest method of estimating savings when properly performed, as has been shown, it is very easy to go astray when performing computerized simulation of buildings. In addition, such standards would work to "blunt" the forces of the marketplace which rather strongly "encourage" optimistic estimates of savings (as demonstrated by California's Alameda County's lawsuit with a contractor whom the county themselves naively encouraged to present inflated savings figures, it is unfortunately sometimes impossible to "sell" an honest, but conservative estimate of savings to a potential buyer of an energy retrofit project to an owner who has inappropriate expectations). Such standards might embody the following as minimum requirements:

- Quality control measures should be used to critique existing building model, including:
  - annual energy use comparison
  - seasonal variations graphed and compared
  - hourly demand should be graphed and compared (perhaps only on larger projects)

- Existing building modeling documentation should include:
  - complete input file
  - key portions of the output file (for programs like DOE-2, TRACE and the like, the output printout can be almost unlimited in extent, making inclusion of the entire output impractical)

- Retrofit modeling documentation should include
  - revised input file
  - key portions of the output file
  - comments describing the changes made from the existing (or prior model) and explanations of the changes

Those practitioners intending to employ computerized building simulation in their energy analyst practice, should forearm themselves with appropriate training in the business. In order to assist the industry in achieving the benefits promised by computerized building simulation, a training seminar has been developed by the author to improve the skills of engineers and energy analysts in performing computerized building simulation, <u>regardless of the specific computer program in use</u>. In the course of his 20 years as a practicing energy engineer, the author has developed a concise set of procedures and practices which, when followed, regularly produce very accurate building simulations as well as very accurate estimates of potential energy savings - as demonstrated by his numerous projects producing savings as projected.

ABOUT THE AUTHOR

James P. Waltz, President of Energy Resource Associates, Inc., is an acknowledged pioneer in the field of energy management. Prior to the Arab Oil Embargo of 1973, Mr. Waltz made a personal commitment to energy management as a principal focus of his engineering career. Since that time, he has served as energy management program manager for the Air Force Logistics Command and the University of California's Lawrence Livermore National Laboratory. In addition he has worked as an energy management engineer for consulting and contracting firms. In 1981 he founded Energy Resource Associates for the purpose of helping to shape the then-emerging energy services industry - and did so through a multi-year assignment to create a successful energy services business unit for a Fortune 500 temperature controls manufacturer.

Specializing in the mechanical, electrical and control systems of existing buildings, Mr. Waltz's firm has accomplished a wide variety of facilities projects, recently including a corporate-wide energy management program review for a major hospital chain, design of replacement chilled water plants for two northern California hospitals, on-site recommissioning of the entire building automation system for another large northern California hospital, audit and expert testimony relating to a failed energy services contract for a large southern California hospital, and DSM project quality control and performance review and HVAC training for a California utility company.

Mr. Waltz's credentials include a Bachelors Degree in Mechanical Engineering, a Masters Degree in Business Administration, Professional Engineering Registration in three states, charter member of and Certified Energy Manager of the Association of Energy Engineers (AEE), member of the Association of Demand Side Management Professionals (ADSMP), Demand Side Management Society (DSMS) and the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE).

Mr. Waltz was named International Energy Engineer of the Year for 1993 by the Association of Energy Engineers.

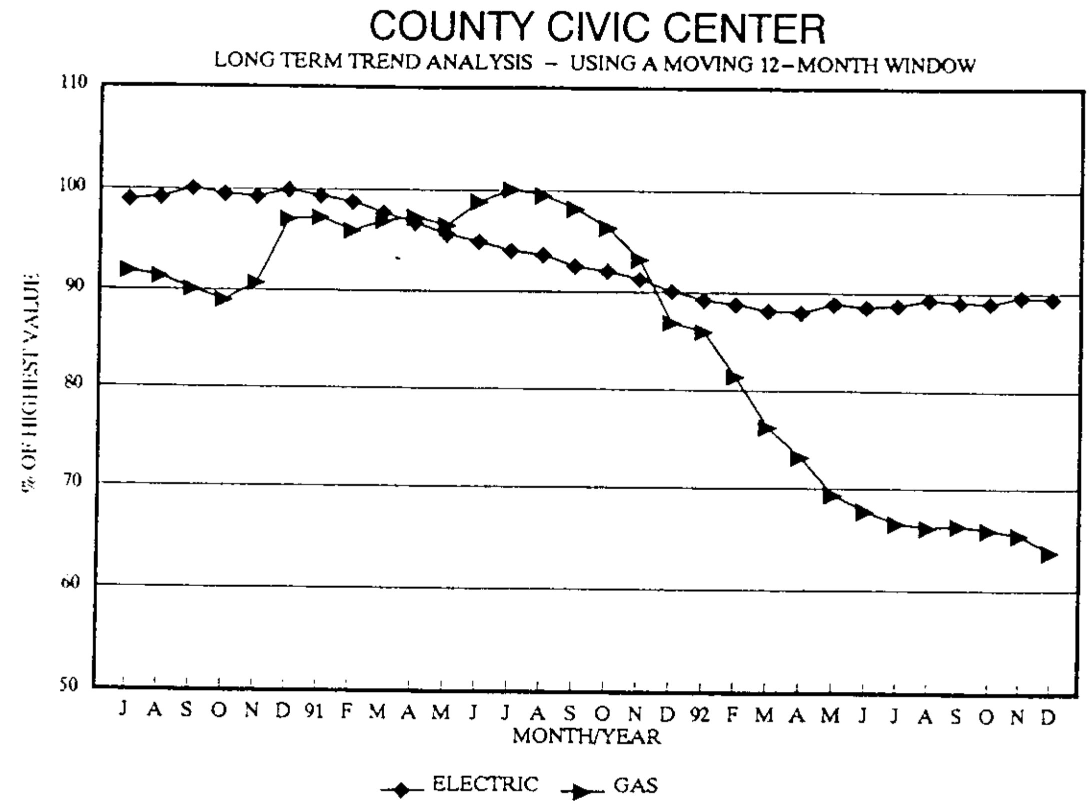


FIGURE 1.

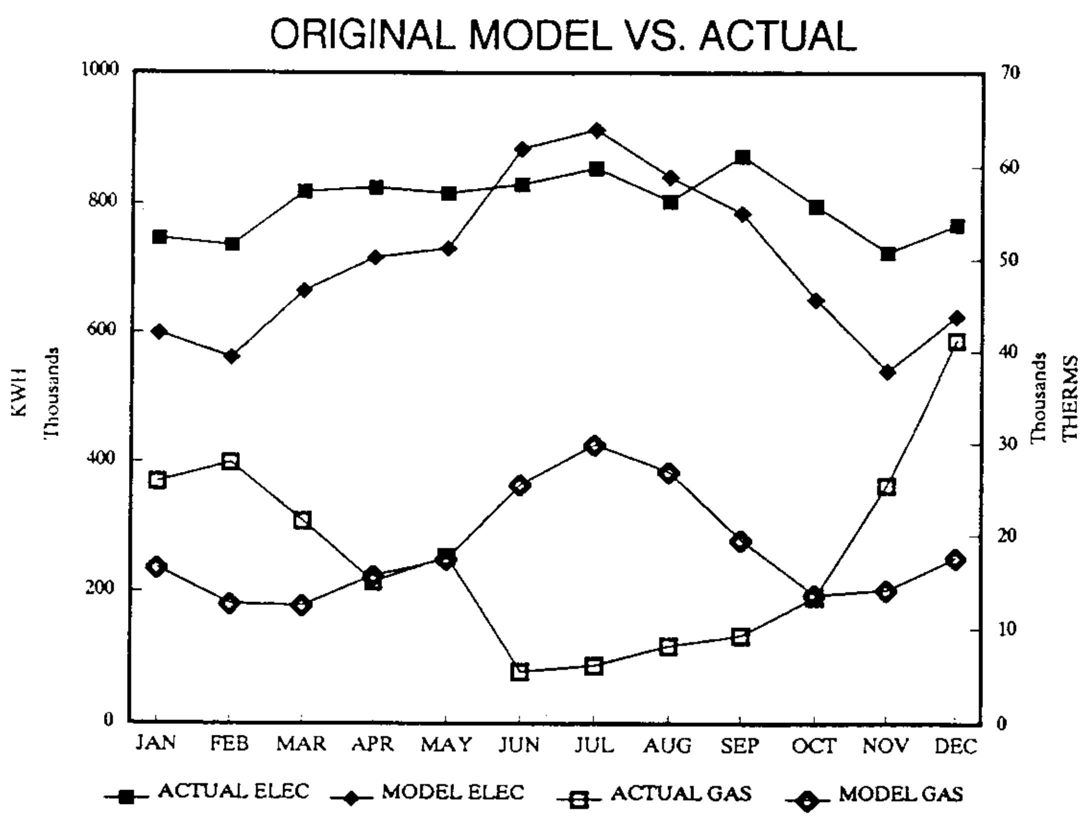


FIGURE 2.

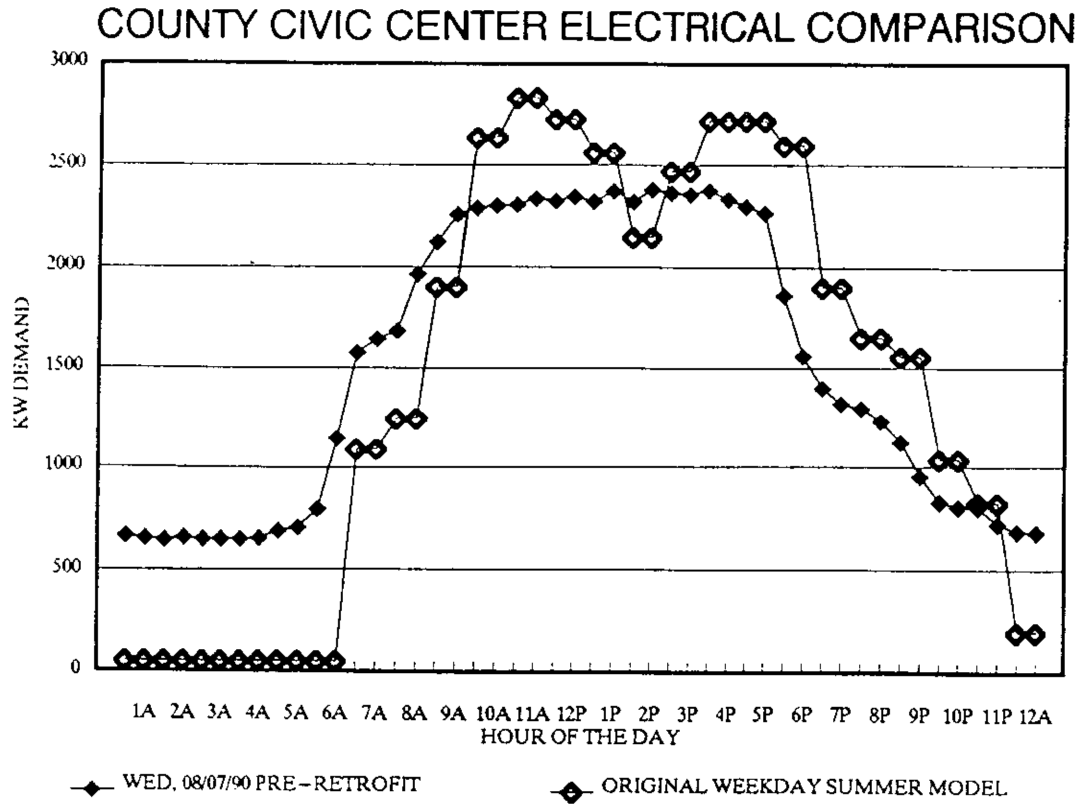
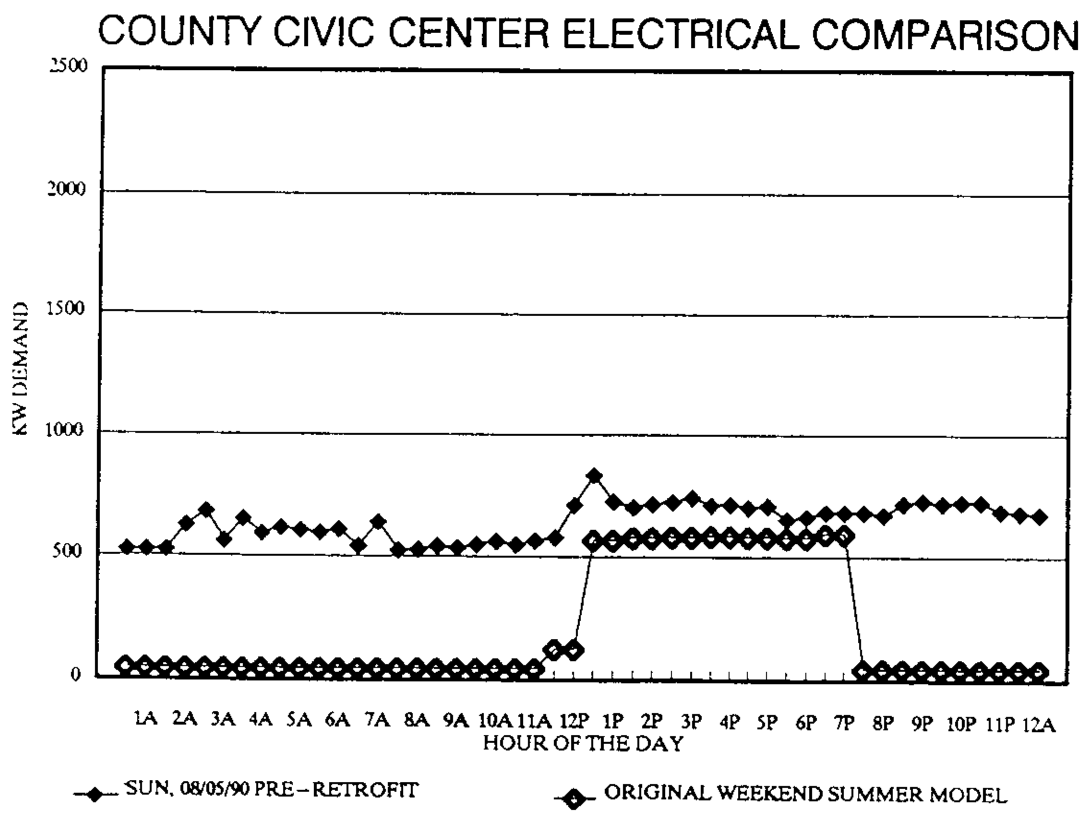


FIGURE 3.



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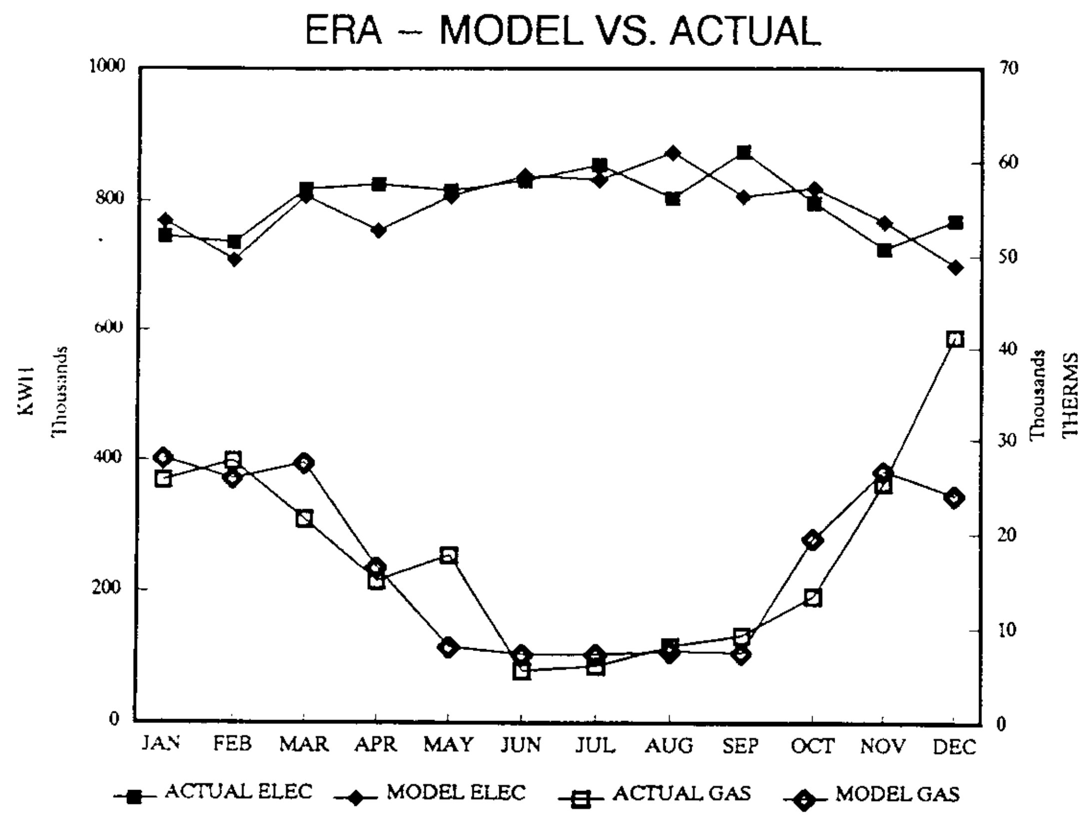

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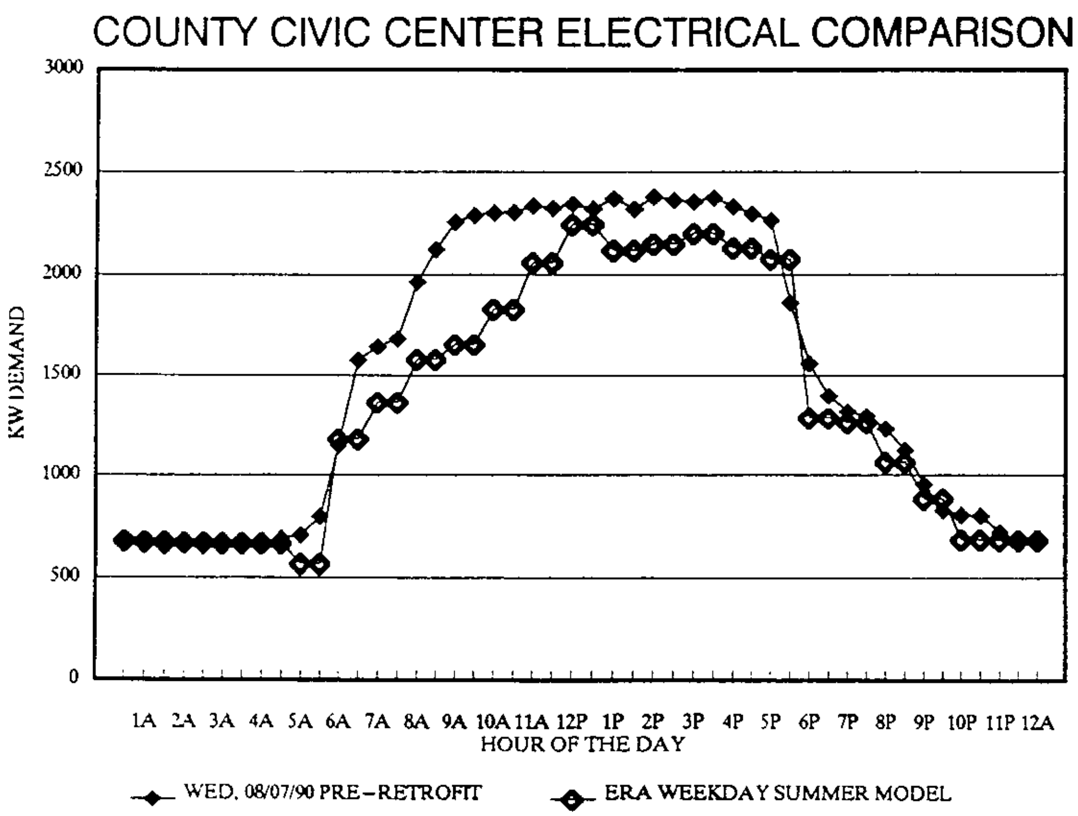

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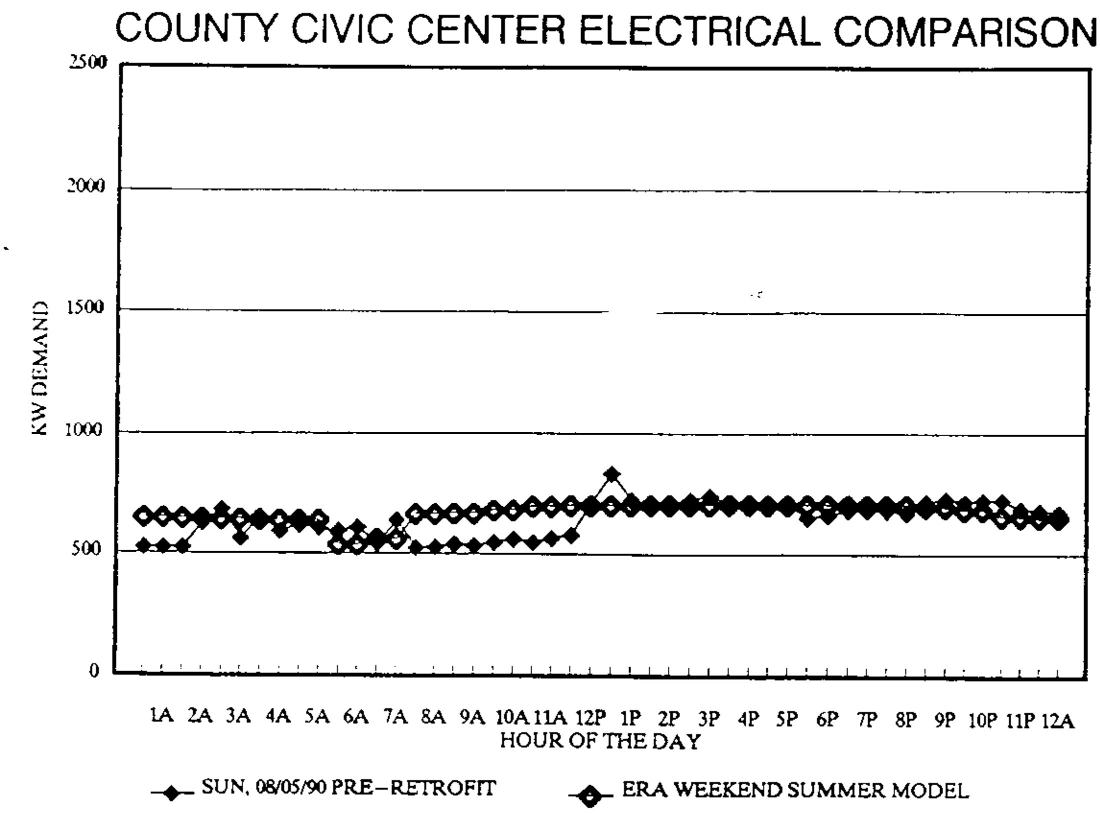

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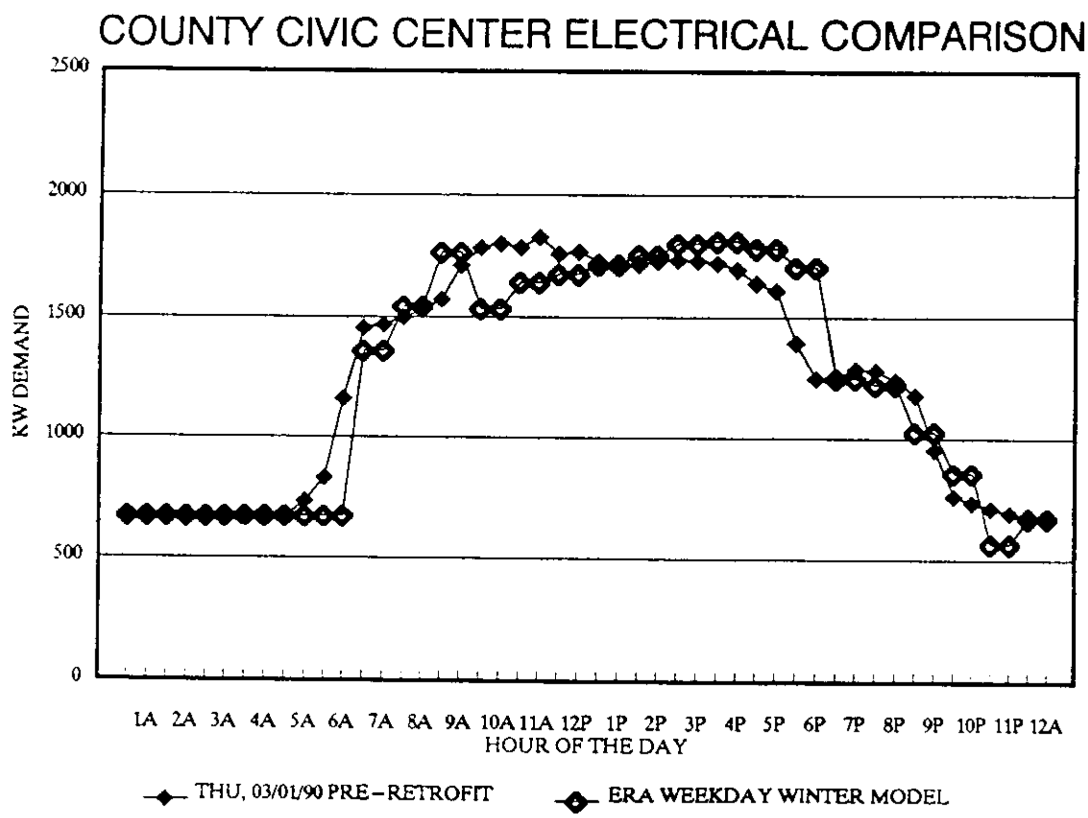


FIGURE 8.

---------------- CALCULATION SHEET ---------------- DATE: 04/13/93
(SAV-SUM) INIT: JPW

SUMMARY OF SAVINGS FROM SIMULATION:

ENERGY USE CATEGORY	ENERGY UNITS	EXISTING BUILDING MODEL	RETROFIT BUILDING MODEL	SAVINGS	PERCENT REDUCTION
FANS					
-HOJ OFFICES - SF	KWH	692757	170665	522092	75.4%
-HOJ OFFICES - RF	KWH	80394	66569	13825	17.2%
-HOJ JAIL - SF	KWH	66596	66596	0	0.0%
-HOJ JAIL - RF	KWH	16629	16629	0	0.0%
-HOJ JAIL - EF	KWH	13140	13140	0	0.0%
-HOJ SHERIFF - SF	KWH	162791	41438	121353	74.5%
-HOJ SHERIFF - RF	KWH	22692	20423	2269	10.0%
-HOJ COMPUTER - SF	KWH	50712	50712	0	0.0%
-HOJ STORAGE - SF	KWH	22807	22807	0	0.0%
-HOJ STORAGE - RF	KWH	5702	5702	0	0.0%
-HOJ LOBBY - SF	KWH	35929	35929	0	0.0%
-ADMIN BLDG - SF	KWH	149486	120908	28578	19.1%
-ADMIN BLDG - RF	KWH	6584	6035	549	8.3%
-ADMIN BLDG - EF	KWH	4500	4125	375	8.3%
SUBTOTAL FANS	KWH	1330719	641678	689041	51.8%
COOLING PLANT	KWH	896341	707428	188913	21.1%
PLANT AUXILIARIES	KWH	239229	239229	0	0.0%
COOLING PUMPS	KWH	521310	493790	27520	5.3%
HEATING PUMPS	KWH	156376	156376	0	0.0%
LIGHTS	KWH	2796416	2796416	0	0.0%
OTHER ELECTRIC	KWH	2841000	2841000	0	0.0%
MISC. ELECTRIC	KWH	700800	700800	0	0.0%
SUBTOTAL ELECTRIC	KWH	9482191	8576717	905474	9.5%
SPACE HEATING	THERMS	199996	87447	112549	56.3%
DOMESTIC WATER HEAT	THERMS	5933	5933	0	0.0%
SUBTOTAL GAS	THERMS	205929	93380	112549	54.7%

	ELECTRIC	GAS	
TOTAL SAVINGS	905474	112549	
PLAUSIBILITY FACTOR	1.00	0.80	
NET SAVINGS	905474	90039	
NET PERCENT REDUCTION	9.5%	43.7%	
VALUE AT CURRENT AVG UNIT COST	$82,398	$52,223	=$134,621 TOTAL SAVINGS

--------------------ENERGY RESOURCE ASSOCIATES----------------------

TABLE 1.

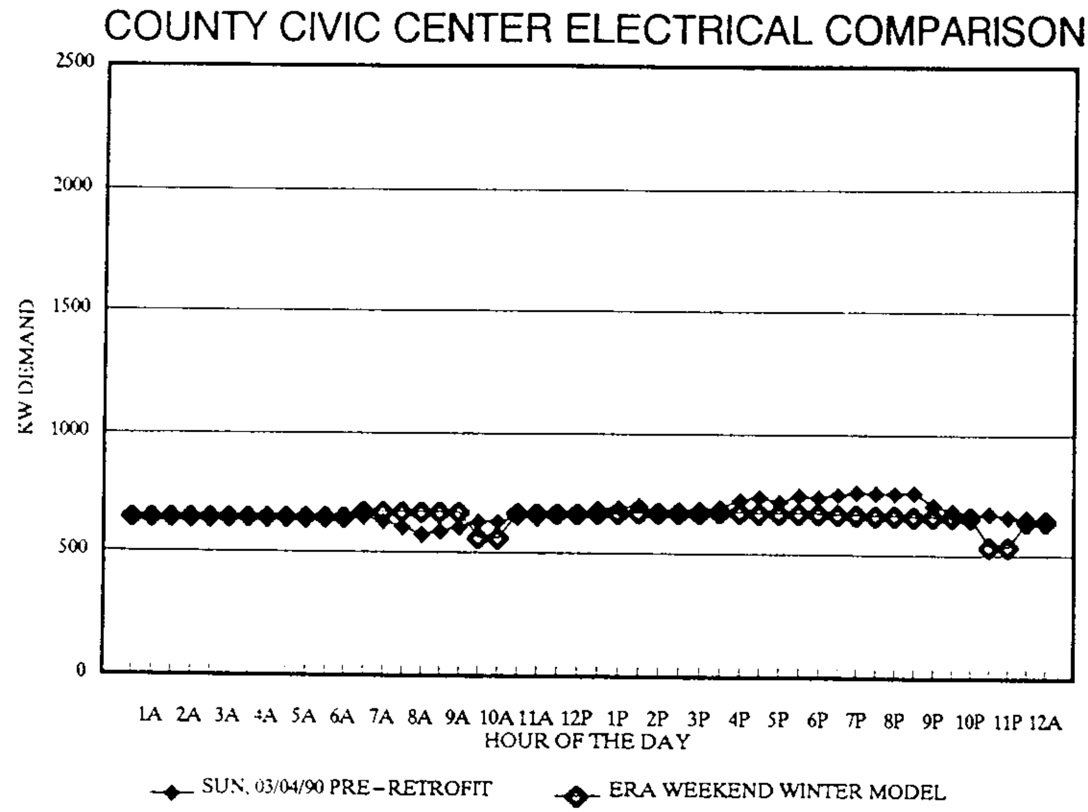


FIGURE 9.

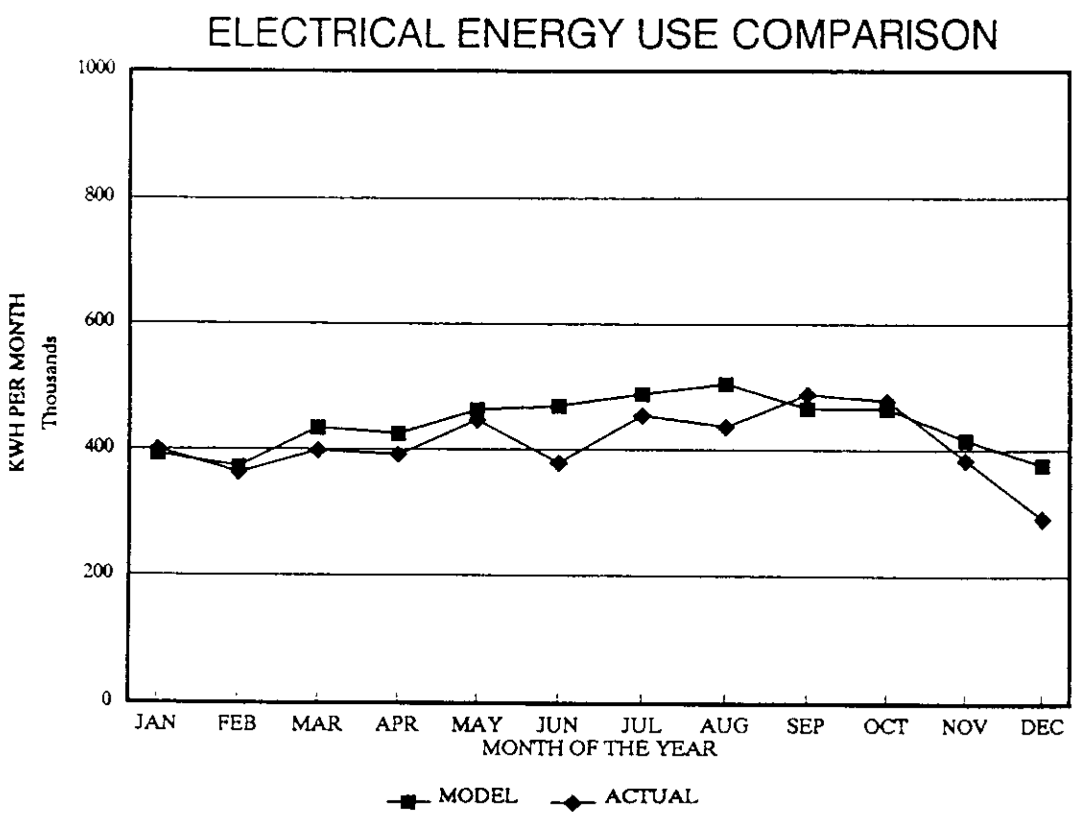
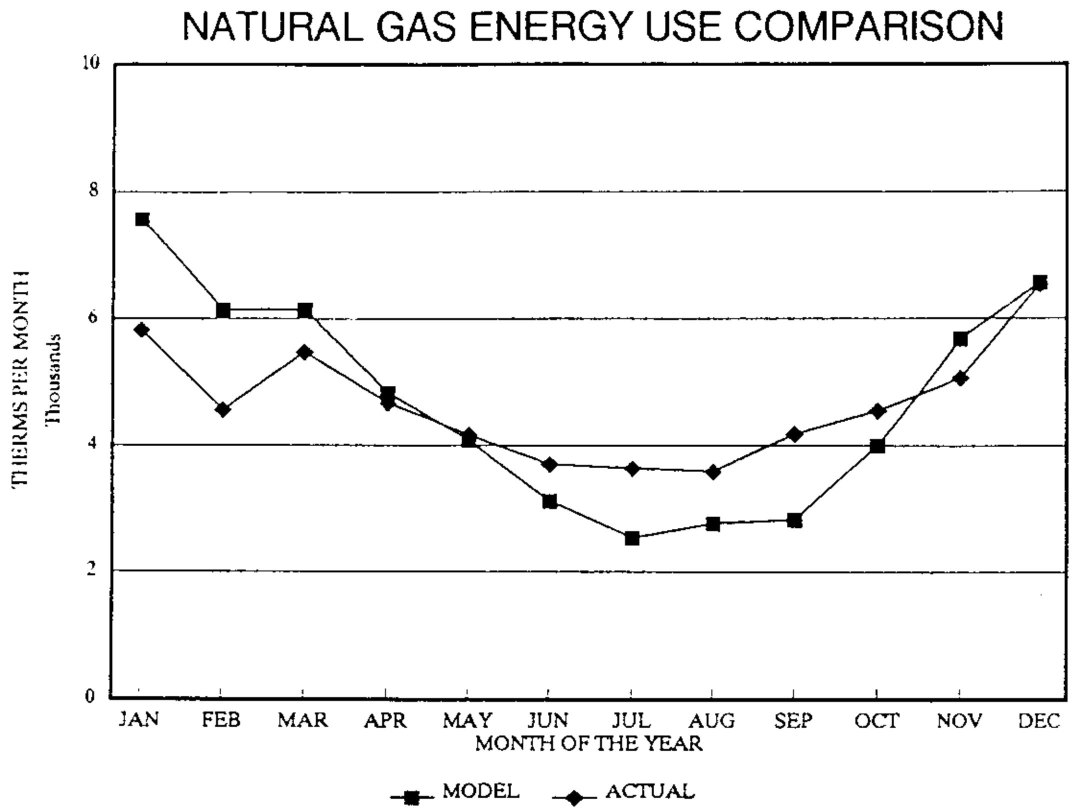


FIGURE 10.



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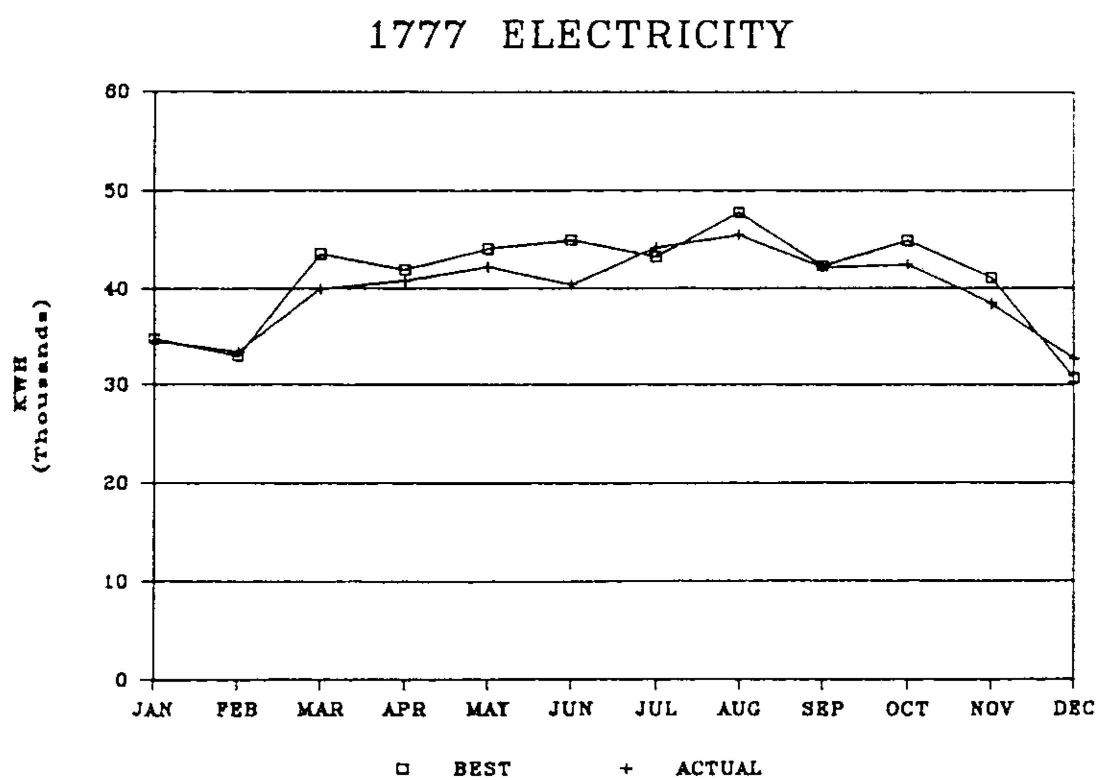

FIGURE 12.

1777 NATURAL GAS

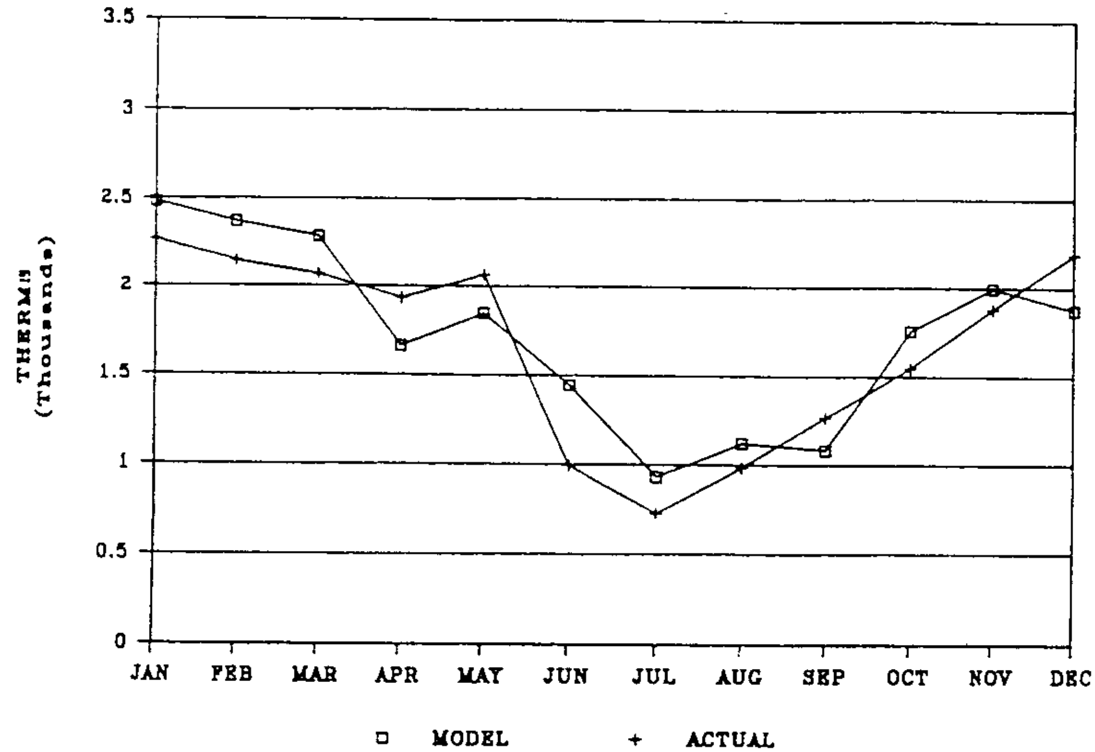

FIGURE 13.