Session 2533

Building Energy Analysis Software

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Effective utilization and conservation of the significant energy used by building systems has been of great impor in the decades following the energy crisis of the 1970's. The energy consumption of the heating, ventilating, and conditioning (HVAC) system represents a major part of the building's requirements. Software for accurately evaluating the performance of various types of HVAC systems and of the available energy saving options proves useful both for the design engineer and for classroom use in HVAC courses as well. Existing programs were fou be either too complicated (expensive) or were unable to consider one or more of the major energy/demand reduc techniques available today. The HVAC simulation program reported herein will handle all major types of energy recovery and/or peak shaving schemes in combination with any of today's main types of terminal HVAC systems The PC program, utilizing actual hourly weather data, allows the student (or design engineer) to examine the mar possible combinations and interactions of types of HVAC terminal systems and energy saving options in one or r geographical locations. As example results demonstrate, type of system, combination of options, building characteristics, and location all influence the overall energy performance and thus the "best" selection. The addit of one energy saving option may reduce or even negate the savings otherwise available from other installed energ conserving equipment. The methodology allows exploring the interactions and selecting appropriate equipment on either energy consumption alone, or on life cycle cost.

INTRODUCTION

Effective utilization and conservation of energy have been of great importance in recent decades because of the energy crisis of the 1970's. The quickest and the most accurate way to evaluate an energy saving idea is by using the computer. The HVAC simulation program developed for this project significantly reduces the time required to analyze various energy saving ideas against a base case (no energy saving option).

With this software, five types of HVAC systems (or terminal systems) can be simulated. These HVAC systems are:

- Variable (or constant) air volume system with (or without) reheat
- Dual duct/multizone (2 deck) system
- Four-pipe fan coil system
- Triple deck multizone system
- Closed water loop heat pump system

As an example, Figure 1 provides as schematic of the dual deck multizone systems with several energy saving options.

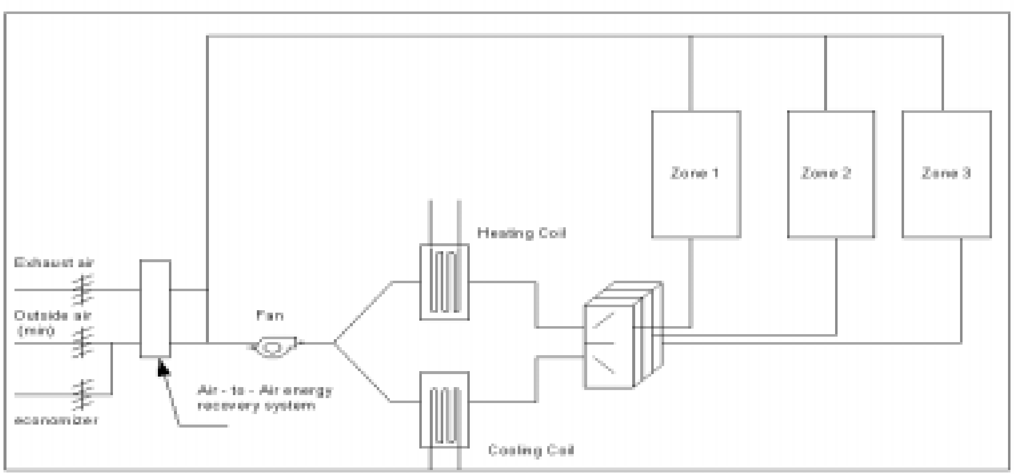


Fig. 1 - Schematic of multizone system with economizer and air-to-air energy recovery equipment.

The following energy conserving options can be selected, either singly or in combination, for each type of terminal system:

- Air side economizer
- Water side economizer
- Heat reclaim with/without thermal storage
- Air-to-air energy recovery equipment
- Cold thermal storage

Each of these is discussed in more detail in the following section.

ENERGY CONSERVATION OPTIONS

The various energy conservation options that can be analyzed using the software developed for this project are:

Option 1: Air side economizer
Option 2: Heat reclaim
Option 3: Both with air side economizer priority
Option 4: Both with heat reclaim priority
Option 6: Air-to-air energy recovery system without air side economizer
Option 7: Air-to-air energy recovery system with air side economizer
Option 8: Water side economizer
Option 9: Cool thermal energy storage

All these options are available for each terminal system except the closed water loop heat pump, which itself is inherently an energy conserving system.

Air Side Economizer

Air side economizers are used frequently to get free cooling with outside air. In the air side economizer cycle, a variable position damper is controlled by a temperature or enthalpy sensor ahead of the cooling coil. When the enthalpy of the outside air is less than that of the return air, more (than the minimum ventilation requirement) outside air is brought in for free cooling. This results in less load on the cooling coil. The air side economizer damper is used in conjunction with a fixed minimum outside air damper which provides minimum ventilation all the time. The air side economizer will save only cooling energy. The use of an air side economizer is expected to increase total HVAC energy in dual duct and multizone systems because the heating load in cold climates increases as more outside air is brought in for free cooling of interior spaces. This increase in heating energy can be avoided by having separate outside air ducts for the hot deck and the cold deck.

Water Side Economizer

Water side economizers are also used to get free cooling from outside air. However, in this case the performance is tied to the wet bulb temperature of the outside air rather than the actual air temperature. Free cooling in water side economizer operation is obtained by using cooling towers, often in conjunction with a plate type heat exchanger, to provide the chilled water for the cooling coil.

Heat Reclaim

A heat reclaim or heat recovery system is one which intercepts and utilizes heat which would otherwise be " wasted " to the atmosphere. In all but tropical climates most large buildings require cooling in interior zones and heating in exterior zones at the same time during some periods of the year. The heat rejected at the condenser in the refrigeration plant, otherwise wasted, can be a source for part of this heating requirement. An additional amount of heating is provided from a supplementary heater if the rejected heat is insufficient. On the other hand, heat is rejected at the cooling tower if the heat produced by the mechanical cooling system is more than needed. Thermal storage may be provided. When water chillers are used, a special *double bundle condenser* can be used to recover the waste heat.

Economizer and Heat Reclaim Combination

Economizer and heat reclaim cycles may work against one another when used together in a system. When an air side economizer or a water side economizer is used, less cooling is required and consequently the heat rejected at the condenser reduces. Hence the energy saving by heat reclaim reduces if this heat could have been used. Two control strategies may be employed with the combination of economizer and heat reclaim. Priority could be given either to the air side economizer or to the heat reclaim cycle.

<u>Priority to Economizer Cycle.</u> In option 4, the air side economizer cycle is given the priority. Heat available for reclaim is less than in Option 3 (only heat reclaim). There are savings in cooling energy as compared to Option 3 because the air side economizer is used. But the savings in heating energy decreases due to the use of air side economizer.

<u>Priority to Heat Reclaim Cycle.</u> To minimize total annual HVAC energy both techniques should be combined such that energy-saving effect is maximum. In heat reclaim priority, the air side economizer is used only up to the point where its reduction of heat reclaim starts increasing heating energy.

Air-to-Air Energy Recovery

Exhaust air is discharged from the HVAC system so that required ventilation air can be brought into the building. The exhaust air is close to the thermal condition of the conditioned room whereas the incoming ventilation air may be far from the desired conditions of humidity and temperature. The outside air can be hot and humid in summer and cold and dry in winter. This incoming air has to be treated to maintain the comfort conditions inside the zone. Figure 2 shows the addition of an air-to-air heat exchanger in the system for pretreatment of the outside air using exhaust air.

The effectiveness of the air-to-air energy recovery system is defined as the ratio of the actual heat transfer to the thermodynamically limited maximum energy transfer in a counterflow energy exchanger with infinite transfer area. There are two types of effectiveness for air - to - air energy recovery system. One is sensible effectiveness for recovering the sensible heat and other is latent effectiveness for recovering the latent heat (moisture) from the exhaust air.

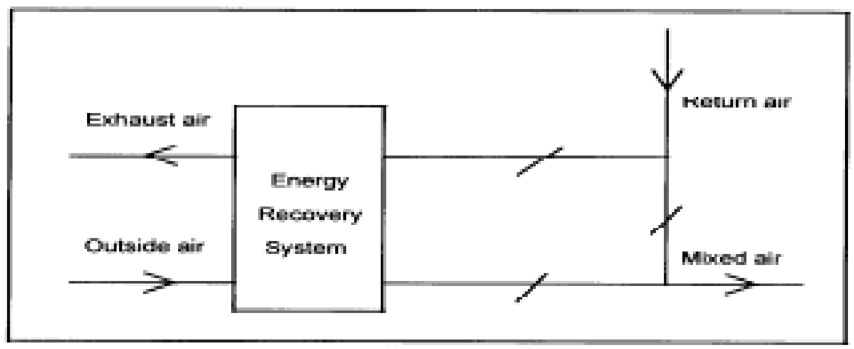


Fig. 2 - Addition of energy recovery system to an HVAC system

Cool Thermal Energy Storage (TES)

The three normal options of cool TES operation are: Full Storage, Load Leveling and Demand Limiting. In full storage the entire utility-peak load is shifted to off peak time. The chiller runs at its maximum capacity during the utility off-peak period and is switched off during the day. In load levelling a smaller chiller will run continuously at its maximum capacity throughout the day. When the cooling produced is more than the load at any point of time, the excess cooling energy will be added to the storage. For periods when chiller capacity is insufficient, cooling is augmented from storage. In the demand limiting option, the chiller is utilized during the peak period, but not to its full capacity. If the chiller is run at its full capacity during the peak period, then it is equivalent to the load leveling option. Hence, a 100% value on demand limiting represents a load leveling and a 0% value represents full storage option.

SYSTEM SIMULATION PROGRAM

To simulate any HVAC system, the first requirement is hourly building loads. The building subprogram used in this project to calculate hourly loads was developed by Anantapantula [1]. The terminal system subprograms use the hourly loads obtained from the building subprogram and input data from the systems file (input file given by the user for different terminal systems). Terminal system cooling, preheating, heating, and/or reheating as well as fan needs are calculated by this subprogram. The primary systems subprogram takes the information calculated by the terminal subprogram and computes energy requirements of the chiller and the supplementary heater. Figure 3 shows the organization of the system simulation subprograms.

The software is compiled in Visual C++. The Visual C++ environment makes the software more user friendly with the help of dialog boxes. For the simulation of a system, the executable file (HVAC.EXE) and several input files are required. Visual C++ pops up an

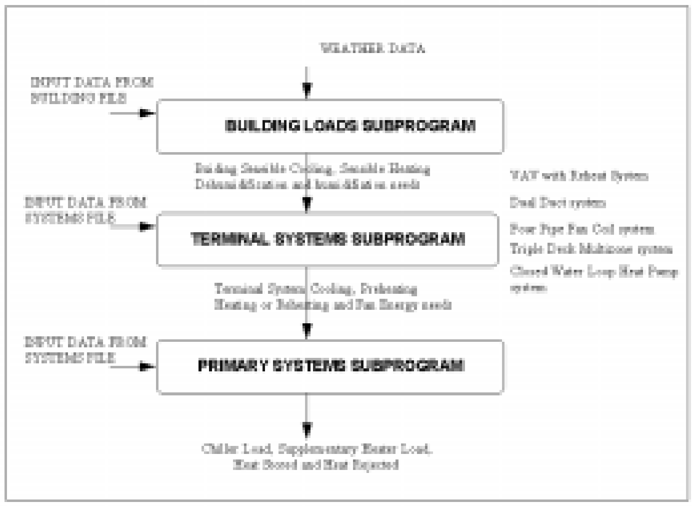
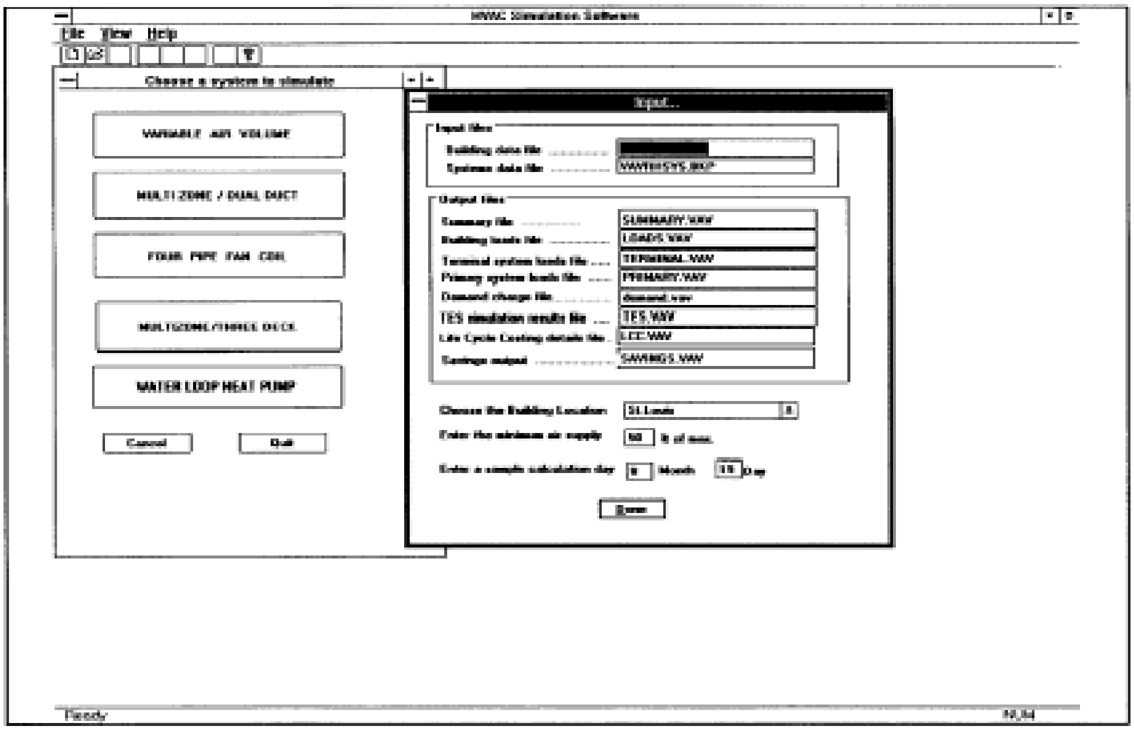


Fig. 3 - Organization of simulation program.

error message if any of the input files are missing.   The software has a run time of approximately three minutes on a Pentium PC when simulating a system with all the energy saving options considered.   Data output files are generated which can be viewed using the " Edit Files " option in the File Menu or from an external editor. Figure 4 illustrates the dialog boxes that appear on the screen. The first dialog box shows the various HVAC systems that can be chosen for simulation in this project. After selection of the system, an input dialog box along with the default value for that system appears on the screen. Names and paths for input data files and output data files are entered in this dialog box.

Buildings and their HVAC systems can be simulated at different geographical locations. If a city other than the default (St. Louis) is chosen, then the weather data files for that location need to be entered. Another dialog box allows selecting various energy saving options appear on the screen.



Input Files. For simulation of any terminal system, a **building data file**, a **system data file** and the **weather data files** are required. The building data file contains the inside design conditions, the operational hours of the HVAC system, areas, U-values, numbers of people, internal loads for each zone. Any number of building spaces can be handled. The required system data file contains the operational characteristics (e.g., efficiencies) of the heating and cooling equipment, the HVAC system operating points, ventilation air requirements, and all cost data. The required weather data consist of three files, each containing hourly air temperature and humidity level plus solar and wind data. One is for the cooling design day and a second one is for the heating design day. A weather data file consisting of hourly values for the entire year is required to do the economic analysis on the system.

Fig. 4 - Input dialog boxes.

Output Files. Each system simulation generates six output files: LOADS, PRIMARY, TERMINAL, SAVINGS, DEMAND, and SUMMARY. The LOADS file gives the hourly values of the building loads for a sample calculation day specified by the user. It also contain annual total values of building cooling need, heating need and the dehumidification need. The PRIMARY file contains the hourly values of primary system loads for a sample calculation day. Also the annual chiller energy, supplementary heating energy, heat rejected and the fan energy are printed in this file. All these values are printed for each option of energy saving that is chosen by the user. The TERMINAL file contains the sizing information for the system simulated. It has the zonal requirements for the supply air and the minimum outside air. The hourly terminal loads for a sample calculation day for all the energy saving options that are selected are printed in this file. Also it has the annual total values of terminal cooling energy, preheating energy, reheating energy and the fan energy for each of the options. The SAVINGS file has the annual energy estimates for different energy saving options. Also, it has tables showing the savings in annual energy and percent savings with respect to base case for all those options. The economic analysis done on these options is also printed in this file. The DEMAND file contain the peak load, energy, demand charge, energy charge and total charge for each month. These values are printed for each energy saving option that is selected. The SUMMARY file prints the location of the building, the terminal system that is used and the design and operating conditions for the system. The internal load, hours of operation, building parameters and various energy saving options are also printed in this file. Annual energy use and maximum demand can also be obtained from this file. This file contains the equipment sizes (chiller, boiler, and fan) for the various options. It also has the percent savings and the life cost parameter for the energy saving options. With this file it is very easy to compare various systems at different locations.

SAMPLE RESULTS

The main goal has been to provide a convenient mechanism for comparing the various energy saving options for common types of terminal systems including: VAV with reheat, dual duct, four pipe fan coil, triple deck multizone, and the closed water loop heat pump. One sample set of runs was made to compare different terminal systems at one location. Additional sets of runs were made to compare one terminal system with various energy saving options at four different locations. Locations chosen are St. Louis (moderate), Minneapolis (cold), Phoenix (hot and dry) and Houston (hot and humid).

All these runs are compared using the annual energy consumption (kWh /ft^2) and percent savings in annual energy. Total annual HVAC energy (kWh) was divided with total floor area (ft^2) to make annual energy consumption independent of building size. Chiller size parameter (ft^2/ton) and unit boiler size (Btuh/ft^3) are also compared. For comparing the chiller size parameter, total area (ft^2) was divided by chiller capacity (tons) and total capacity of the boiler was divided by the volume of the building to get the unit boiler size. As the chiller size (tons) increases, the chiller size parameter (ft^2 /ton) decreases and vice versa.

Comparison of Different HVAC Systems at One Location

Figure 5 shows annual energy consumption (kWh/ft^2) and percent savings in annual energy for various terminal systems at St. Louis. It can be seen that the triple deck multizone system is the best system at St. Louis when used in combination with the air side economizer and heat reclaim with heat reclaim priority (Option 4). Also, Option 4 is the best energy saving option for all the systems except the four pipe fan coil system where the air side economizer (Option 1) is best.

Figures 6 and 7 show the chiller size parameter (ft^2/ton) and unit boiler size (Btuh /ft^3) for all systems at St. Louis. It can be seen that the four pipe fan coil system with an air - to - air energy recovery system has the lowest chiller and boiler size. For the four pipe fan coil, maximum cooling load and maximum heating load are less than that of the other systems. Air is first cooled, even in zones requiring heating with the VAV with reheat system and, hence, chiller size for this is more than four pipe fan coil. The boiler size reduces for Options 2 and 4 because in this option heat is reclaimed. In the dual duct system mixing of cold air and hot air takes place, which increases the chiller and boiler size. In the triple deck multizone , hot/cold air is mixed with return air which reduces the chiller and boiler size as compared to the dual duct system.

Comparison of One System in Different Locations

Geographical location greatly effects the performance of energy savings options for various terminal systems. Annual energy (kWh/ft^2) and percentage savings graphs are again used to compare a terminal system at St. Louis, Minneapolis, Houston and Phoenix. The base case (with no energy saving options) is first compared for these locations.

In Figure 8, the VAV with reheat system is compared at four locations. For the base case, annual energy consumption is maximum at Minneapolis. This is expected because Minneapolis has an extremely cold climate with high heating load. Combination of the air side economizer and heat reclaim with heat reclaim priority (Option 4) is the best energy saving option at all four locations. This option saves about 48 % of annual energy savings in Minneapolis and St. Louis but for Houston this saving reduces to 30 %. This is because more heating is required at Minneapolis and St. Louis as compared to Houston and heat reclaim operation reduces the heating load.

Effects of Thermal (Hot) Storage with Heat Reclaim and Economizer

Hot storage is a simple and effective way of both reducing equipment size and conserving energy. Heat rejected at the condenser is used to heat a large storage tank of water. Hot storage was included along with heat reclaim and the air side economizer for the VAV with reheat system in St. Louis, to study the effect of hot storage on annual energy consumption. In the VAV with reheat system when hot storage was used along with heat reclaim and air side economizer with priority given to heat reclaim, savings in cooling energy was observed. This is due to the fact that when hot storage was available, the economizer was able to operate more often without reducing the effect of heat reclaim. It can be seen from Table I that percentage savings obtained with hot storage are not much for the VAV with reheat system in St. Louis. The savings of 0.1% does not justify the additional cost of heat storage.

Table I. Savings when hot storage is used with heat reclaim and economizer with heat reclaim priority for VAV with reheat system at St. Louis

Hot storage (number of days)	Annual Cooling Savings (kWh)	Annual HVAC Savings (kWh)	Percentage savings in HVAC energy (%)
0	85909	577075	48
1	86390	577556	48.1
2	86390	577556	48.1

Combination of Heat Reclaim, Hot Storage, Air-to-Air Energy Recovery, and Economizer

Hot storage (1 day storage) is examined in combination with heat reclaim, air-to-air energy recovery system (sensible effectiveness = 70 % and latent = 50 %) and an air-side economizer. Priority is given to heat reclaim operation. This is done for the VAV with reheat system in St. Louis. Table II shows the effect of the combination. This combination is compared with Option 4 (combination of air side economizer and heat reclaim with heat reclaim priority). Savings increase by 1.2% when hot storage and air - to - air energy recovery is included. Again the increase is not much and may not justify the additional cost of hot storage and air-to-air energy recovery equipment. However, a reduction in chiller size is another benefit of the addition of air-to-air energy recovery.

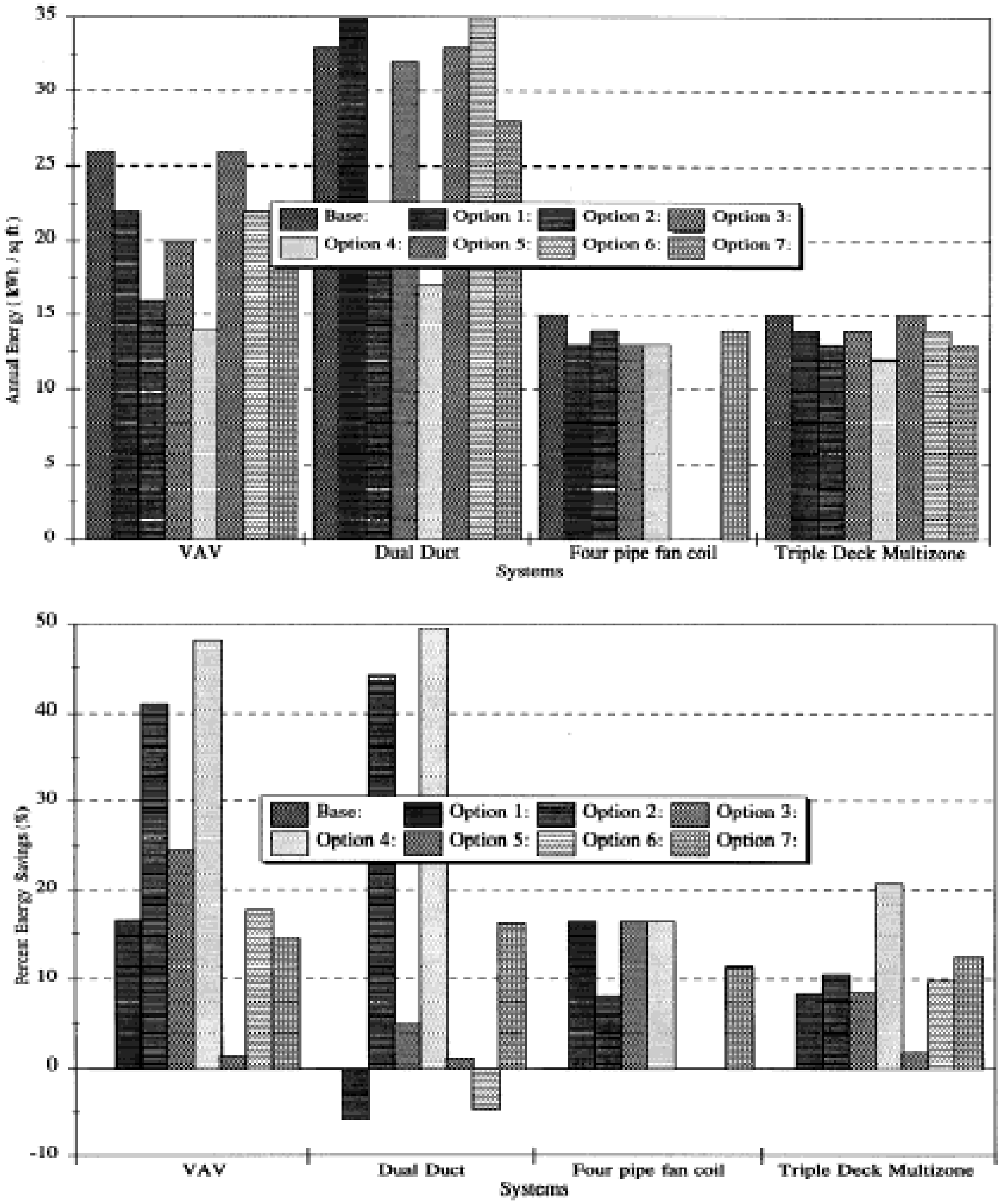


Fig. 5 - Annual energy usage & savings for various systems & options - St. Louis.

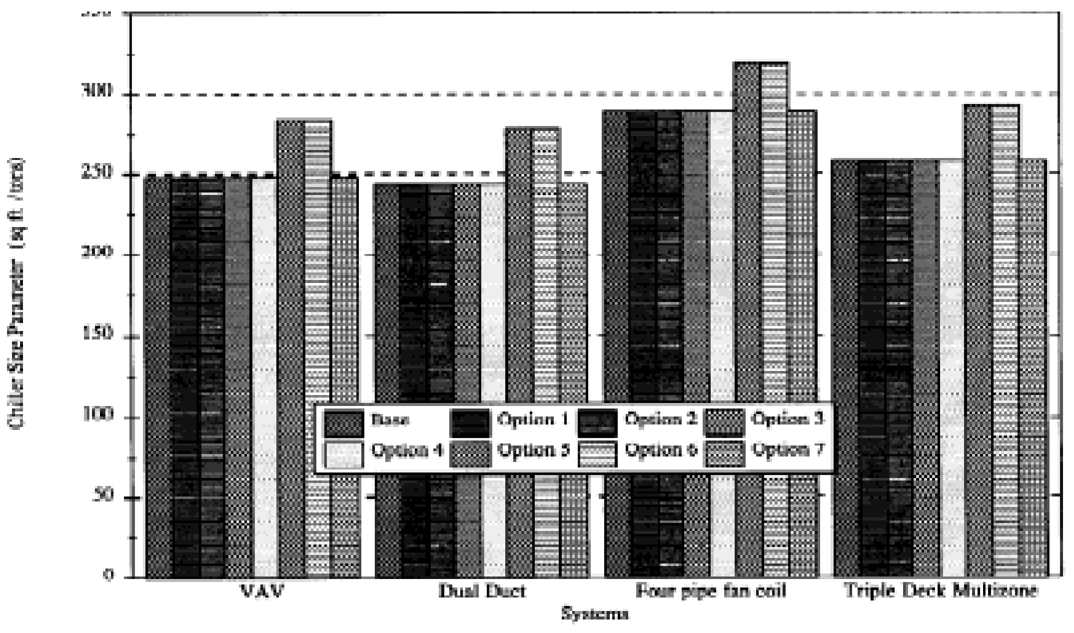


Fig. 6 - Variation in chiller size parameter - St. Louis.

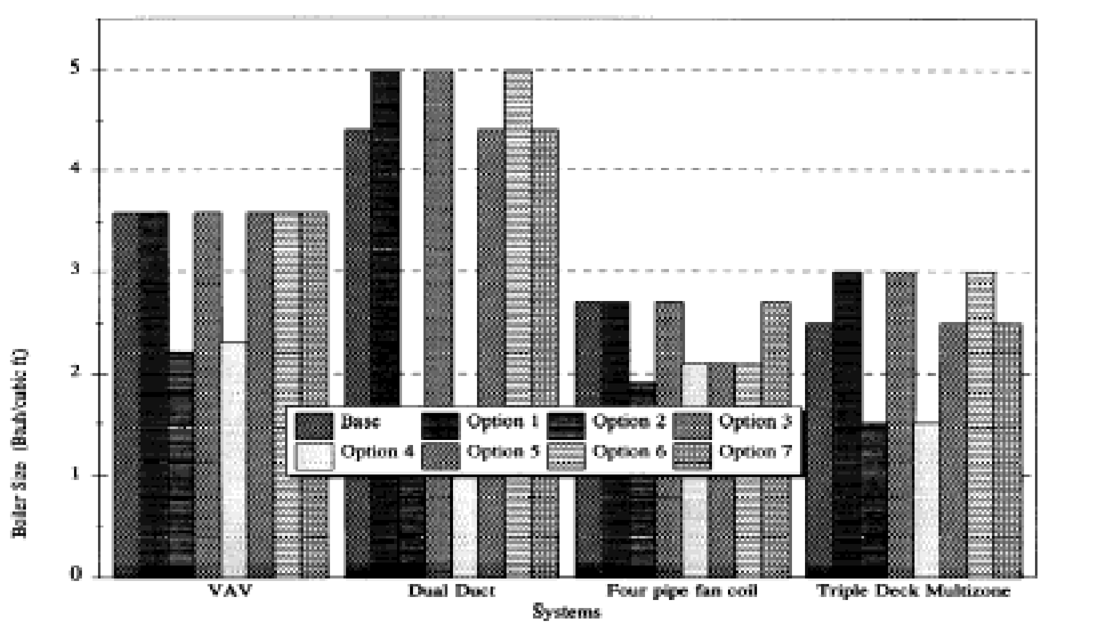


Fig. 7 - Variation in boiler size - St. Louis.

Fig. 8 - Annual energy usage & savings for VAV system at different locations.

Table II. Performance with economizer, heat reclaim, hot storage, and air-to-air energy recovery for VAV with reheat system in St. Louis

Option	Chiller (ft^2/tons)	Heating Energy (kWh)	Cooling Energy (kWh)	% savings
economizer and heat reclaim	249	40110	442748	48
economizer and heat reclaim with hot storage and air - to - air energy recovery	284	40110	427578	49.2

CONCLUDING COMMENTS

The software developed under this project should prove useful in engineering courses which include the concepts of energy conservation, particularly in building systems. The program requires minimum input and yet the results from the simulation of an actual 16-zone office building in St. Louis, Missouri, compare quite favorably with actual utility company data [2].

From the example data presented in this paper, comparative results for the energy usage of various HVAC system types and energy conserving equipment are obtainable, Specific examples of the types of conclusions that users would obtain are:

- Performance of energy saving options depend upon the terminal system used. This can be seen from the fact that the combination of economizer and heat reclaim with heat reclaim priority gives maximum savings for the VAV with reheat, dual duct, and triple deck multizone systems. When the four pipe fan coil system is used, the air side economizer gives the maximum savings.
- Geographical location also greatly affects the performance of energy saving options. For example, the water side economizer is least effective in Houston but at Phoenix it is most effective. This is due to the fact that more free cooling hours are obtained in Phoenix than in Houston.
- The air side economizer does not save energy in dual duct and triple deck system if cold outside air is allowed to go to both the cold deck and the hot deck. Heating energy increases when more outside air is taken for free cooling. The increase in heating energy is more than the decrease in cooling energy. {Note: A recent article by Liu, Claridge, and Park [3] discusses the problem and a solution.}

The methodology (and corresponding software) allows exploring the interactions of various conservation methods and selecting the appropriate equipment based on life cycle costs with an accuracy that should make it a useful tool for design engineers as well as the engineering student.

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BIOGRAPHIES

HARRY J. SAUER, JR. is Professor of Mechanical and Aerospace Engineering at the University of Missouri-Rolla. Academic experience includes teaching and research in the thermal science or energetics field, with particular emphasis on heat transfer, energy conversion and conservation, and HVAC (heating, ventilating, and air-conditioning) systems.

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