TRAKLOAD -- ENERGY ANALYSIS AND ENERGY AUDITS IN COMMERCIAL BUILDINGS

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ABSTRACT - TrakLoad EAS is a microcomputer-based analysis and report generation system for commercial building energy audit and management services. TrakLoad evaluates energy cost and use patterns for an audited facility, calculates costs, savings, and paybacks from a set of energy conservation retrofits recommended by an auditor, and provides both engineering and financial reports. Over 100 retrofits can be explicitly analyzed for different types of buildings, including office, retail, apartment, industrial, schools, and restaurants. Applications include: Commercial and Apartment Conservation Service (CACS); energy management for commercial, institutional, and industrial facilities; utility incentive and marketing services; shared savings and third party financing engineering & economic analyses; consulting engeneering services; audit services for new and existing buildings; plan checking and code compliance testing by state, municipal and utility officials.

INTRODUCTION

The rapidly growing use of microcomputers in the professions has brought new opportunities and new challenges to applications software engineers. While limitations of computing power and, to a lesser extent, of memory, have forced the simplification of many energy calculation steps, the high available throughput for input/output operations have allowed the creation of user-friendly interfaces that would be impossible to implement on a time-sharing system or very costly on a dedicated mainframe port.

TrakLoad is such a microcomputer program, designed for energy analysis and energy audits of new and existing commercial buildings. Its principal features are: (1) high speed of calculation, (2) ease of use, (3) engineering support during input through dynamic and cascading defaults, (4) interface with Lotus 1-2-3 for graphics and post-processing, (5) integration of "Loads," "Systems," and "Plant" portions of energy analysis into one package, (6) multiple specification of retrofits as part of building inputs.

This paper summarizes the concepts and functions of TrakLoad's user interface, its principal calculation steps and its energy auditing features.

USEABILITY

When two engineers enter and analyze the same building on the same computer program, most likely their respective results will differ. Such differences can usually be traced to one or more of:

1. Input errors (wrong surface areas, wrong equipment efficiency);
2. Ambiguous inputs (do U-values include surface air film coefficients or not, are wall areas exclusive of window areas?);
3. Engineering judgement (what values to specify for reflectance of indoor surfaces or thermal mass of furniture).

Of these, only the first could conceivably be blamed on the user. The incidence of the second type of differences, ambiguous inputs, can be minimized with good instruction manuals and with the user's familiarity with the design tool.

By far the greatest source of errors is the large number of required inputs and the frequent inability of users to determine unique, let alone correct, values for such inputs, because of the lack of adequate supporting reference material or because such references -- handbooks or workbooks -- indicate ranges of values instead of single numbers for the required inputs. To minimize the incidence of such errors, TrakLoad uses the concepts of dynamic and cascading defaults, and of user environments.

Dynamic and Cascading Defaults

Dynamic defaults are default answers supplied by the computer to its own questions that change in function of answers to other questions. For example, suppose the user answered successive questions about the layers found in a wall construction with: "face brick," "100 mm block," "150 mm fiberglass insulation," "gypsum board." When prompted for the "Wall U-value," rather than calculating the value from handbook tables (a cumbersome and error-prone process) the user should be able to summon the dynamic default of 0.248 W/K-m^3 (0.044 Btu/hr-F-ft^3). If one or more wall layers are changed, the computer recalculates the new U-value instantly. Of course, the user can always override dynamic defaults with a different value.

Similar examples of dynamic defaults can be quoted for most other building inputs: the shading coefficient of window systems, the fan size required by the HVAC system, the efficiency and size of required heating and cooling equipment. Each time, the dynamic default value supplied by the computer is identical to what the user would obtain through meticulous use of tables and working formulas from the ASHRAE Handbook of Fundamentals. Dynamic defaults contribute to ease-of-use, overall speed, and reduction of ambiguities from different choices for the same input by different users.

User Environments

Different user environments are made possible by dynamic defaults. Energy auditors and design engineers, to quote but two different classes of users, have different requirements for a energy analysis program. While an auditor may want to enter different wall construction details and types of windows as noted during an on-site visit to the ding, an engineer may prefer to enter U-values and shading coefficients without bothering with the detail of the actual wall construction.

TrakLoad lets both types of users have it their way. From an internal master list of required inputs, TrakLoad presents only the subset appropriate to the user class and uses dynamic defaults to "fill in the blanks", thus simplifying the use of the program without simplifying its internal calculations. (Of course, the assumptions made by the program through its dynamic defaults can be made visible at any time and overridden if necessary.) An example of this approach is shown in Fig. 1 below:

Master List	Answers	Auditor's Subset	Engineer's Subset
A: Wall Area.....	52 m^3	A: Wall Area	A: Wall Area
B: Orientation...	East	B: Orientation	B: Orientation
C: Outer Surface.	Face Brick	C: Outer Surface	G: Wall U-value
D: Insulation....	150 mm Fiber	D: Insulation	H: Effective Mass
E: Inside Layer..	100 mm Block	E: Inside Layer	I: Wall Color
F: Inner Surface.	Gypsum Board	F: Inner Surface	J: Wall Group
G: Wall U-value..	0.248 W/K-m^2	I: Wall Color	L: Specific Lkg.
H: Effective Mass	31.6 kJ/K-m^2	K: Wall Leakage	
I: Wall Color....	Dark		
J: Wall Group....	A (ASHRAE)		
K: Wall Leakage..	Tight		
L· Specific Lkg..	1.1 cm^2/m^2		

Fig. 1: Example of two user environments: auditor and engineer. The master list of input questions and the subsets for each user enviroment are shown. TrakLoad answers the invisible questions with dynamic defaults.

Other User-friendly Features

In addition to dynamic defaults, TrakLoad's user interface is characterized by:

1. Interactive inputs (computer asks questions, user answers them);
2. Instant error checking (computer rejects inappropriate or inconsistent answers immediately);
3. On-line help (computer explains questions on demand and gives background information);
4. Random-access inputs (change any input and rerun the altered building immediately without having to re-enter other inputs);
5. Few and simply organized "levels" (the number of menus leading to more sub-menus is kept at a minimum).

MONTHLY ENERGY CALCULATIONS

Bins and Monthly Calculations

TrakLoad calculates monthly energy use separately for three periods: Unoccupied, Occupied, and Prime (an optional period during which a different electric rate schedule may be specified). The monthly energy demand rates are calculated for each month for a "snapshot hour" that can be specified by the user for each season.

Loads and HVAC performance are calculated for each period (Occupied, Unoccupied, Prime) and for each 5 degF temperature bin occurring in the climate specified.

In order to save computer time, transmission loads, solar gains and internal gains are calculated for each period for four special temperature bins: Warmest Bin, Cooling Intermediate, Heating Intermediate, Coldest Bin. A linear interpolation is used to compute the same loads at all other bins, as shown in Fig. 2 below.

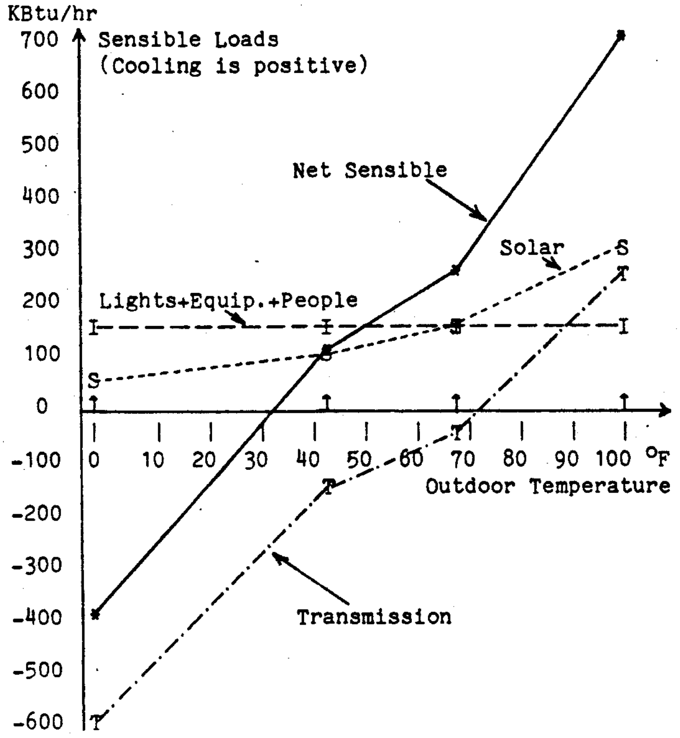

Fig. 2: Schematic example of net sensible load calculation as the sum of transmission and gains from solar, lights, equipment, and occupants, evaluated at four special bins.

The TrakLoad engineering report shows monthly results of loads and energy consumption in units of Btu or kWh. Since the loads and energy consumptions calculated with the bin method are for each bin and are in units of Btu/hr and kW, these bin-by-bin results must be allocated to all those months that "contain" the corresponding bin, by multiplying each result by the number of hours this bin occurs in a particular month. This process is repeated for all bins and for all periods.

LOADS

Net sensible loads

The net sensible load (cooling if positive, heating otherwise) is the algebraic sum of heat transmission, solar heat gain, and sensible internal heat gains from lights, equipment and people. (The latent cooling load will be calculated in the "Systems" portion using the rate of moisture generation in the space and the minimum outside air setting.)

$$\begin{aligned} SENSLOAD = {} & FLRTR + ROFTR + WALTR + GLZTR \\ & + GLZSHG + LITHG + EQPSHG + OCCSHG \end{aligned}$$

where:
FLRTR = Heat transmission through floor, Btu/hr
ROFTR = Heat transmission through roof, Btu/hr
WALTR = Heat transmission through walls, Btu/hr
GLZTR = Heat transmission through glazing, Btu/hr
GLZSHG = Solar heat gain through glazing, Btu/hr
LITHG = Heat gain from lights, Btu/hr
EQPSHG = Sensible heat gain from equipment, Btu/hr
OCCSHG = Sensible heat gain from occupants, Btu/hr

The calculation of each term in this equation is described below. Individual variables are explained only the first time they are used.

Equipment, Lights, and Occupants

To calculate the cooling loads from lighting, equipment, and occupants, TrakLoad looks up the appropriate values from the Cooling Load Factor Tables 17, 19, 22, and 23 (Ch. 26, 1985 ASHRAE Fundamentals). The lookup rows in the tables for lights, equipment, and people are calculated conform to the occupancy durations and the "on-times" and (in the case of lights) to the floor mass and furniture characteristics specified by the user. The lookup columns (hours since turning on lights or equipment, or hours since people entered space) conform to the snapshot hour specified by the user. For the other three periods, TrakLoad "loops" through each hour of the period and accumulates the total cooling load factor for the period.

The heat gains from lighting, equipment and occupants are each subdivided into two components: a steady-state component assumed to be constant 24 hours a day (equal to the Unoccupied heat gain level from each source) and a variable component assumed to be on during the Occupied and Prime periods only and equal to the difference between Occupied and Unoccupied heat gain levels. All cooling load factor calculations are done only for the variable component, and the results added to the steady state component.

For example, a building with a lighting usage factor of 90% of installed capacity (Watt) during occupied hours and 5% of installed capacity during unoccupied hours, is modelled assuming 5% of installed capacity is on 24 hours a day and contributes an equivalent, constant sensible cooling load. The other 85% is assumed on during occupied and prime hours only and its hour-by-hour sensible cooling load is calculated using cooling load factors.

Sensible cooling loads from occupants are evaluated analogously: the occupants during the unoccupied period, if any, are assumed to be present 24 hours a day. During the occupied and prime periods, only the excess number of people as compared to the unoccupied period is considered for cooling load factor calculations.

Effective Thermal Mass

Thermal mass affects heating and cooling loads by delaying and dampening the impact of solar heat gains and of equipment and lighting loads. An additional effect is the inertia the building shows after a HVAC night shutoff or a morning reheat. The first effect is handled in TrakLoad through extensive use of Cooling Load Temperature Difference Factors and Cooling Load Factors, as described earlier. The latter effect is handled with the concept of effective thermal mass.

The effective thermal mass of a building surface is similar to the diurnal heat capacity defined by J.D. Balcomb as "the daily amount of heat, per unit of surface area, that is stored and then given back per unit of temperature swing" within one 24-hour period.[1]

Time Constants

Another important concept, derived directly from the effective thermal mass, is the time constant of a surface. To define it, imagine a one-dimensional building surface in complete thermal equilibrium with its environment, with constant, but not necessarily equal, surface temperatures and constant and equal surface heat flows. Now suddenly change the heat flow through the indoor-facing surface to a new level and hold it there. The surface temperature will jump rapidly at first, then more gradually, until it eventually settles to a new equilibrium. The time constant is the time it takes for the surface temperature to go 1/e=63.2% of the way to eventual equilibrium.

The time constant is calculated as the product of effective thermal mass and overall thermal resistance, including air film resistances on both surfaces.

TrakLoad uses time constants in two instances: (1) to properly identify ASHRAE wall groups used in determining wall CLTD Factors; (2) to estimate the indoor temperature decay after a winter night shutoff of the HVAC system. For the latter, the effective thermal mass, is computed by adding all floor, roof, and wall effective thermal masses of all zones served by this system. Similarly, the time constant, is calculated as the ratio of effective thermal mass and the combined "UA-value" of all zones served by this system.

HVAC System Night Shutoff and Morning Pickup Loads

If the HVAC system is shut off during unoccupied hours TrakLoad assumes a constant Cooling Load Factor of 1.0 during occupied hours and 0.0 during unoccupied hours, as recommended in the ASHRAE Fundamentals.

Moreover, for all "winter bins" (colder than the midpoint between intermediate cooling and intermediate heating bins) TrákLoad estimates the decay of interior temperature, the reduction of the unoccupied heating load, and the additional morning pickup load on the heating system to restore the interior temperature to daytime levels.

If the HVAC system is shut off during the unoccupied period in winter, TrakLoad assumes that the temperature floats downward until it hits the "Winter Night Temperature" specified by the user. Whether it hits that temperature during the unoccupied period, how large the night savings will be and to what extent they may be offset by the additional morning reheat load is a function of: the extent and the duration of the setback, the indoor-outdoor temperature difference, the effective thermal mass and the heat loss coefficient of the building.

TrakLoad assumes that during a winter night setback the indoor temperature falls exponentially from a starting temperature (the winter setpoint) to a fictitious, asymptotic temperature (the outdoor temperature increased by the "free heat" given by any internal gains during the unoccupied period). Depending on thermal mass, building shell conductance, outside temperature and degree of setback the time to reach the setback temperature may or may not exceed the duration of the unoccupied period. TrakLoad calculates how much heat was released from the building to the room air during the setback. The same amount of heat is assumed to be needed the following day to bring the room temperature back up to the setpoint.

The sensible heat load during setback is calculated as the steady-state load at setback temperature minus the heat released from the building to the room air. If the difference is negative, then the result is a zero heat load.

The additional pickup load on the system at the beginning of the occupied period is calculated by assuming that the heat released during the unoccupied period has to be restored to the building mass during the first hour of occupancy (usually the design hour).

For the calculation of the design heating coil capacity the greater of pickup load or heating load at the heating design hour is used. For the monthly calculations the pickup load is added to the sensible load computed without setback.

Air Infiltration

During operation of the HVAC system all fresh outside air is assumed to be introduced mechanically into the space through the outside air intake, at a rate specified by the minimum outside air setting or by the economizer schedule, if any. Cracks and leaks in the envelope are assumed to contribute to air exfiltration only, causing no additional cooling or heating load.

Natural air infiltration through cracks and envelope leaks takes over during HVAC shutoff. To estimate natural air infiltration we use the method developed by Sherman and Grimsrud at Lawrence Berkeley Laboratory.[2]

Only the heating load resulting from air infiltration is calculated; the net cooling load when the HVAC system is shut off (including the portion due to infiltration) is assumed to be zero.

HVAC SYSTEMS

The current version of TrakLoad recognizes 14 types of central and zonal systems:

Central Systems:

1. Terminal Reheat
2. Ceiling Bypass
3. Variable Air Volume (VAV)
4. Power Induction Units
5. Dual Duct or Multizone
6. Dual Duct with Variable Air Volume
7. Variable Temperature Constant Volume
8. Roof Top Unit

Zonal Systems:

9. Fan Coils, 2-pipe
10. Fan Coils, 4-pipe
11. Unit Ventilators, 2-pipe
12. Unit Ventilators, 4-pipe
13. Incremental Heat Pumps on a Water Loop
14. Packaged Terminal Air Conditioning

Central systems are those that collect the return air from all zones in a common return air plenum, recondition it and send it back to heat and cool all zones in different proportions. Zonal systems consist of independent units that heat and cool individual zones. Except for the PTAC system, the zonal units are interconnected by one or two water or steam loops.

Below is a summary of the air handling calculations for both groups of systems, with indications of special provisions for particular systems.

Calculations Common to Central Systems

For all given combinations of bin temperatures and occupancy periods, the calculation procedure followsa loop:

1. Find the temperature and humidity ratio of the system supply air leaving the cooling coil. If there is no supply air reset, then the user-specified design conditions are assumed. If an outside air reset or a discriminator reset was specified then supply temperature and humidity ratio are modified (see below).

2. Calculate the supply air volume to each zone. There are significant differences between constant volume systems, variable volume systems and dual-duct systems.

3. For terminal reheat, ceiling bypass, and variable volume systems calculate the zone reheat load needed to compensate for the difference (if positive) between the cooling rate supplied by the system and the net sensible load. Calculate the average zone temperature.

4. Calculate temperature, humidity ratio, and volume of the return air leaving each zone. The temperature depends on the average zone

temperature, the amount of lighting heat vented to the return plenum, and the amount of bypass supply air (ceiling bypass systems only). The humidity ratio is calculated from the supply air humidity ratio, the supply air volume, and the moisture generation in the zone. The return air volume is the supply air volume minus zone exhaust flows, if any.

5. Accumulate all supply and return air flows for all zones on the system; calculate averages of return temperature and return humidity ratio; if there is a discriminator reset, calculate the supply air temperature. Increase the return air temperature by the heat gain from the return fan.

6. Calculate the percentage outside air if there is an economizer or if the system is variable volume, otherwise assume minimum outside air. Using this ratio, and return and outside air conditions calculate the temperature and humidity ratio of the system mixed air (air-to-air heat exchangers or evaporative coolers, if specified, are taken into account at this point). Add the supply fan heat to the mixed air temperature.

7. If the system mixed air temperature is less than the minimum cold supply air temperature, calculate the preheat consumption (if a preheat coil was specified) necessary to raise it to the cold supply air temperature.

8. If the mixed air temperature is greater than the desired cold supply air temperature, calculate the cooling coil consumption necessary to achieve desired cooling coil conditions. If the mixed air humidity ratio is less than the coil design value, then the latent cooling component is assumed to be zero.

9. For systems with reheat, the heating coil consumption is the sum of the zone reheat loads from (3). For systems that do not heat and cool simultaneously, the heating coil consumption is the sum of zone sensible load and incoming outside air sensible load minus supply fan heat. If winter humidification was specified calculate the additional energy necessary to humidify the supply air for winter conditions.

Outside Air Reset Control

This control allows the minimum cold supply air temperature to rise as the outside temperature falls, to compensate for the decreasing cooling demand. It is characterized by a "Reset Temperature," the "Outside Temperature Without Reset" and the "Outside Temperature at Full Reset," as shown in Fig. 3. below.

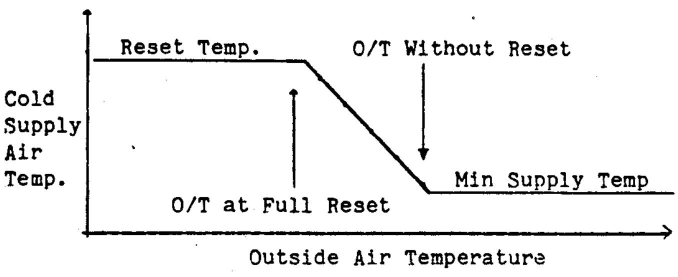

Fig. 3: Cold supply temperature vs. outside air temperature for a system equipped with outside air reset control. The supply air temperature is at the minimum setting during hot weather, then gradually increases to the reset level as the weather gets milder.

Variable Air Volume Systems

In a VAV system both supply and return fans are variable volume. Fan volume is adjusted with one of three control strategies: Speed control of the motor, or discharge dampers or inlet vanes on the fan itself. For each of these three strategies the electric power demand decreases with fan volume, though not proportionately. The relationship between electric power demand and the fan air flow is described by a part load efficiency curve, in the form of a polynomial of part load ratio. For each fan control strategy, the part load efficiency curves used in TrakLoad were taken from DOE 2.1.[3]

Dual Duct and Multizone Systems

The cold and hot deck air flows from a dual duct or multi-zone system necessary to meet the cooling or heating demand in a zone can be thought of as the superposition of two flows: the primary flow is the minimum flow from the cold or hot deck necessary to meet the cooling or heating demand, respectively. The secondary flow is the difference between the fixed air volume provided to the zone and the primary flow. It should have neither cooling nor heating effect, and thus should have a temperature equal to the zone setpoint, which in turn dictates the precise mixture of cold and hot deck secondary flows. The superposition of primary flow and hot and cold secondary flows yield the actual mix of hot and cold deck flows.

Heat Exchangers and Evaporative Coolers

A heat exchanger in TrakLoad is modelled as a generic device that takes heat from the relief air and adds it to the incoming fresh air when there is a heating requirement. The relief air is that portion of return air exceeding the supply air flow. The heat exchanger efficiency indicates how effectively the incoming fresh air is preheated, with 0% representing outside air temperature and 100% representing the theoretical maximum equal to the return air temperature.

The evaporative cooler modelled in TrakLoad is of the direct type, whereby added moisture cools the incoming fresh air stream. Again, a 0% evaporator efficiency indicates that the incoming air remains at the outside dry bulb temperature, while at 100% the incoming air is cooled to the outside wet bulb temperature.

Economizer, Mixed Air Temperature and Humidity Ratio

The function of an economizer is to provide "free" cooling during mild to cold weather by increasing the proportion of outside air. As the outside temperature rises above a user-specified value, the "Economizer Setpoint," the proportion of outside air is reset to the minimum value. The fault value for the Economizer Setpoint is the nimum Cold Supply Temperature" plus 10 F. The economizer cycle is represented schematically in Fig. 4 below.

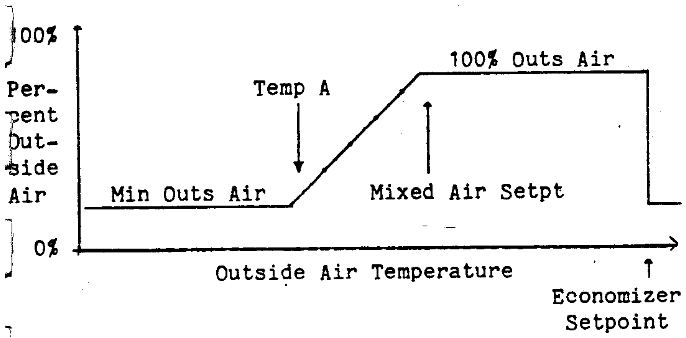

Fig. 4: Percent Outside Air as a function of Outside air temperature for a system with an economizer. As the outside temperature drops below the Economizer Setpoint, the system switches to 100% fresh air. Below the Mixed Air Setpoint, fresh decreases gradually to maintain the mixed air stream at the Mixed Air Setpoint. Below "Temp A", the proportion of outside air is again fixed at the minimum setting.

culations Common to Zonal Systems

Zonal systems consist of decentralized units that heat or cool individual zones independently. Except for the Packaged Terminal Air Conditioning system, the zonal units are generally interconnected by one or two water or steam loops. The Incremental Heat Pump system has a single loop that can transport the heat rejected in one zone that is being cooled to another in need of heating.

The calculations for zonal systems follow a loop similar to that for central systems.

1. Assume that temperature and humidity ratio of the supply air leaving the cooling coil are at design conditions except for the Unit Ventilator system where it is modulated by a valve actuated by a room thermostat.

2. Calculate the average supply air volume to each zone from the number of "on" and "off" cycles except for the Unit Ventilator system where it stays constant at the user-specified value.

3. Calculate humidity ratio and volume of the return air. The humidity ratio is calculated from the supply air humidity ratio and air volume, and from the moisture generation in the zone. The return air volume is the supply air volume minus zone exhaust flows, if any.

4. Calculate the percentage outside air if there is an economizer, or use the user-specified value otherwise. Using this ratio and the return and outside air conditions calculate the mixed air temperature and humidity ratio. Add the supply fan heat to the mixed air stream.

5. Calculate sensible and latent cooling coil consumptions necessary to bring the mixed air temperature and humidity ratio to the conditions determined in (1). Assume zero latent cooling if the humidity ratio of the coil is less than that of mixed air.

6. Calculate the heating coil consumption as the sum of zone sensible load and incoming outside air sensible load minus supply fan heat. If winter humidification was specified calculate the additional energy necessary to humidify the supply air for winter conditions.

Hot Water Consumption

The heating consumption due to hot water heating is calculated from user specifications on hot water consumption, temperature rise, and tank and pipe losses.

If the water heating equipment is of flow-through type this consumption is passed to the space heating equipment selected, usually a boiler. Otherwise, the fuel requirements for water heating are calculated separately by dividing the heat consumption by the equipment efficiency.

Space Cooling Plant

The cooling coil consumption calculated as described earlier is passed to the cooling equipment. The fuel consumption for cooling is calculated using steady-state equipment efficiency specified by the user and part-load performance curves from DOE 2.1.[3] The auxiliary energy consumption for chilled water pump and cooling tower fans and pump, if any, is also calculated at this point. The cooling plant types handled by TrakLoad are:

1. Centrifugal Chiller
2. Absorption Chiller
3. Double Bundle Chiller
4. Direct Expansion, Air Cooled
5. Direct Expansion, Water Cooled
6. District Chilled Water
7. Air-to-Air Heat Pump
8. Water-to-Air Heat Pump

Space Heating and Domestic Hot Water Plant

The sum of preheating, heating, and humidification consumption or any backup from a heat pump is passed to the heating equipment to calculate a fuel consumption for heating. If flow-through domestic hot water was specified or if the cooling plant is an absorption chiller or a heat pumpt, then there are additional contributions to the other heating consumption values. The auxiliary energy consumption for hot water pump, if any, is also calculated at this point. The heating plant types available in TrakLoad are:

1. Boiler
2. Electric Resistance
3. District Heat
4. Furnace
5. Air-to-air Heat Pump
6. Water-to-air Heat Pump

OUTPUT

TrakLoad's output is in the form of monthly and yearly values of the following list of items, each for unoccupied, occupied, prime periods, for 24-hours and for a user-specified "snapshot" hour:

For the whole building:
  Total Electricity Usage, sum of:
    Cooling
    Electric Heating, if any
    Electric Hot Water, if any
    Fans -- HVAC air handlers
    Electric Equipment, if any
    Lighting

  Total Fossil Fuel Usage, sum of:
    Fossil-fueled Heating, if any
    Fossil-fueled Hot Water, if any
    Fossil-fueled Equipment, if any

In addition, monthly estimated fuel bills are shown for these same items, using the user-specified rate schedules.

For each HVAC system:
  Cooling primary consumption
  Cooling auxiliary consumption
  Heating primary consumption
  Heating auxiliary consumption
  Supply Fan consumption
  Supply air flow volume
  Outside air percentage
  Return Fan consumption
  Total sensible loads, sum of:
    Transmission & infiltration
    Solar gains
    Equipment gains
    Lighting gains
    Occupant gains

For each zone:
  Total sensible loads, sum of:
    Transmission & infiltration
    Solar gains
    Equipment gains
    Lighting gains
    Occupant gains

POST-PROCESSING AND GRAPHICS

TrakLoad includes an optional interface with the Lotus 1-2-3 and Symphony programs (both Trademarks of Lotus Development Corporation). With this option, the items described above are automatically reformatted into a Lotus "worksheet", which allows further processing of the results using the electronic spreadsheet feature of these programs. For example, units may be changed and seasonal totals may be calculated with a few keystrokes. This format also provides for an interface with data aggregation and cost estimation programs.

The Lotus interface also includes a set of "macros" that allow producing graphics of the results of a run or of the comparison between two buildings with one or two keystrokes. Printouts of a few typical examples are reproduced below.

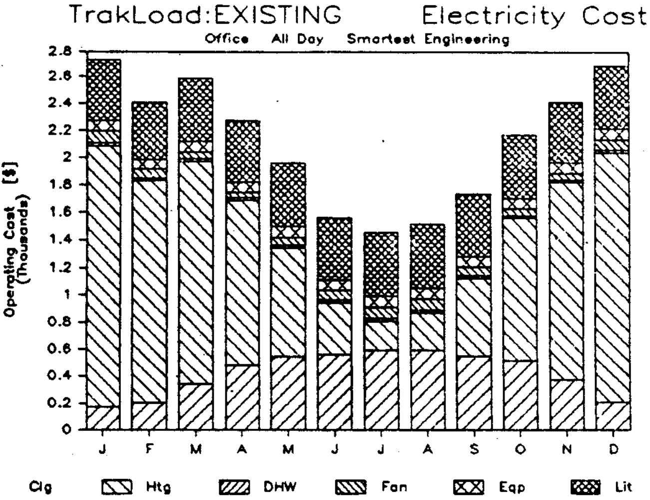

Fig. 5: Monthly electricity bills broken down by end use category for a building modeled "as-is."

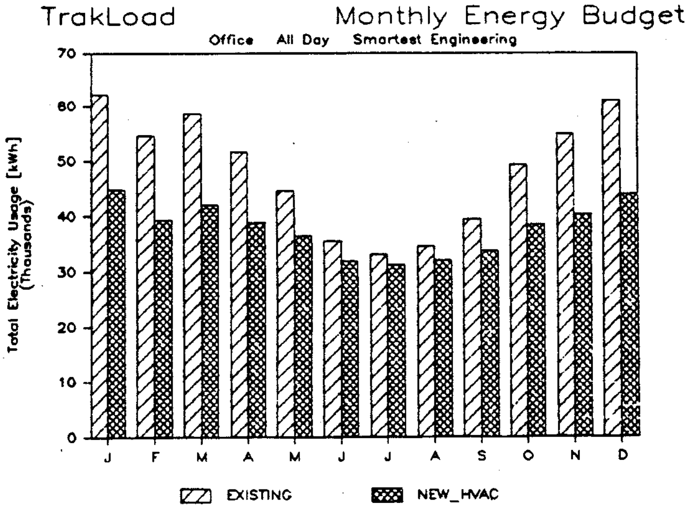

Fig. 6: Comparison of monthly electricity consumption of a building before and after retrofit.

ENERGY AUDITS

For any building specified by the user, the TrakLoad Energy Audit System can evaluate costs and savings from over 100 measures and practices. The auditor selects the retrofits to be tested from a set of simple screen menus. The cost for each measure is entered at the same time, either using the default supplied by TrakLoad or entering an actual value. Default costs are calculated using a library of material and labor prices stored on disk, as well as dimensional information previously specified by the user while entering inputs.

The available retrofits are summarized below:

- **building envelope** (increased insulation, glazing replacement, storm door and window installation, infiltration reduction);
- **lighting** (daylighting, delamping, lighting controls, fixture replacement);
- **equipment** (heat recovery, use rescheduling);
- **use and occupancy** (conditioned space reduction, thermostat setbacks);
- **water heating** (storage insulation, flow restrictors, water temperature reduction, heater replacement);
- **heating and cooling distribution** (pipe/duct insulation, duct sealing, air filter maintenance, system balancing, outside air damper replacement, duct rerouting);
- **heating and cooling plant** (plant replacement, downsizing, burner replacement, burner tuneups, intermittent ignition device installation, vent damper installation);
- **renewables** (thermosiphon air system, sunspace, solar water heating, solar pool heaters).

Costs, savings, and payback periods of the selected retrofits are presented in an Energy Audit Report is a client-presentation document emphasizing the financial impact of a retrofit package, using detailed utility rate schedules. The four-part report contains:

1. an audit financial summary presenting energy costs, savings, and retrofit investment for the facility and for each energy source, with an energy efficiency comparison index;
2. energy use profiles for each end use "before" and "after" retrofit, with an electric peak demand analysis;
3. a payback analysis for each retrofit and for the entire facility;
4. a detailed report for each recommended retrofit, including a retrofit description, individual and cumulative savings, auditor comments, and the impact of the retrofit on all end uses (e.g. the effect of delamping on cooling and heating plant consumption, fans).

This report is printed from a WordStar-like template with "MailMerge" symbols to indicate where the numeric results are to be printed (WordStar and MailMerge are trademarks of MicroPro International Corp.). Accordingly, the report format is completely customizable by the user using common WordStar format and commands.

DISCUSSION

Values for loads and energy consumption predicted by TrakLoad for a small, 5,000 ft^2 (465 m^2) office building with different HVAC systems and placed in different climates were compared with results from DOE 2.1B simulating the same building with the same configuration. Agreement was generally within ±10%. Caution should be excercised, however, in interpreting this type of comparison. Only buildings that can be fully and unambiguously described by all programs being compared should be used as test cases. One would expect lesser agreement for very complex buildings or for very peculiar climates.

CONCLUSIONS

TrakLoad is an energy analysis and energy auditing package for commercial buildings. Its energy calculations follow the modified bin method with extensions in the calculation of air infiltration, solar gains and thermal mass. A considerable portion of the development effort was dedicated to designing the user interface, which features dynamic and cascading defaults and a variety of decision-making aids. As a result, the program brings engineering analysis within easy reach of users without advanced engineering training and may eventually contribute to a more widespread dissemination of energy conservation techniques. Caution must be excercised, however, in accepting results on blind faith obtained by laypersons, as even the "smartest" program can never substitute for good engineering judgement.

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