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Conservation Options in Residential Energy Use: Studies Using the Computer Program Twozone

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CONTENTS

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CONSERVATION OPTIONS IN RESIDENTIAL ENERGY USE: STUDIES USING THE COMPUTER PROGRAM TWOZONE

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ABSTRACT:

A computer model called TWOZONE, which differentiates between the thermal behavior of the north and south zones of a house, is used to study the heating and cooling loads of single-family residences. The model agrees well with the available field data and with the NBSLD (NBSFAST) computer program. In this paper we resolve the furnace output into component loads. We show that depending on the climate, there is an optimum glass area and location in the house from the viewpoint of minimizing the yearly heating bill. The effectiveness of several window management strategies is studied. The energy savings and cost effectiveness of various retrofit measures such as ceiling and wall insulation, storm windows, and clock thermostat are evaluated for two different climates.

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I. INTRODUCTION: ORIGIN AND FUTURE ROLE OF TWOZONE

During the 1975 Summer Study at Berkeley on the Efficient Use of Energy in Buildings, Dean and Rosenfeld (U. California, Berkeley) wanted a simple residential model to use in studying the effect of various design changes on overall energy use. They wrote the original version of the computer program called TWOZONE[1]. It is easy to use and on the LBL computer costs only about $4 to simulate the yearly heating and cooling of a house. The same simulation would cost about $8 on the fast version of NBSLD (NBSFAST). It also contains some useful graphic outputs (samples shown later).

TWOZONE was written before the inception of the joint Cal-ERDA program to write public-domain computer codes for building energy analysis. It will be merged with Cal-ERDA in Phase II, and in its final form will be part of the Cal-ERDA program. Future residential models will consist of three zones (north and south zones plus attic zone) or four zones (north and south zones plus attic and basement zones).

II. PROGRAM DESCRIPTION

The program does an hourly heat load calculation, driven by a National Oceanic and Atmospheric Administration (NOAA) weather tape. The standard ASHRAE algorithms[2], as implemented in the subroutines of NBSLD[3] and NECAP[4] were used to calculate solar radiation from observed cloud cover, the delayed thermal response of walls and ceilings, and the prompt solar heat gain through windows. However, instead of using the weighting factors of NECAP, the program makes the slightly simpler thermal approximations that (1) the house has a lumped heat capacity, adjusted to give a moderately insulated house a relaxation time of 4 hr, and (2) the house has a 3-hr relaxation time for solar heat incident through windows. It should be noted that even NBSLD must be "tuned" with a heat capacity parameter (see Section IIIB).

The house is modeled as a two-zone space, connected thermally by either a fan or by convective air flow, as shown in Fig. 1. This two-zone feature was included because we were particularly interested in capturing solar heat through large south-facing windows and then calculating the economics of moving that heat to the cold north side of the home.

For the case of heating, the losses are due to air infiltration and to conduction/radiation through the ceiling, walls, windows, and floor. The heat sources are the furnace, solar heat gain through the glazing, and internal heat sources such as people, lights, and appliances.

There are three operating modes for the house:

1. If the average inside air temperature (hereafter referred to as T) exceeds T_{HI}, the house "vents" all excess heat, during non-summer months. During summer months, depending on the outside air temperature, the house either "vents" the excess heat, or the air-conditioner switches on to keep the inside air temperature at T_{HI}.
2. If T lies between the furnace thermostat setting and T_H, the house temperature "floats."
3. If T is below the desired thermostat setting, the furnace is "on" until the house temperature reaches the desired setting.

In this way the hour-by-hour energy use can be calculated. The graphics printout of the program can display the hourly energy use along with the hourly inside and outside temperatures; an example is shown in Fig. 2.

In summary, the input to the program consists of the following: a weather tape with hourly data, building description, schedule for internal loads, thermostat settings, and exterior and interior shading. The output contains hourly heating and cooling loads (apportioned to infiltration, walls, floor, ceiling, and windows), cumulative furnace and air conditioner outputs, hourly inside temperature data, and graphical plots showing hourly loads and temperatures.

III. COMPARISONS WITH REAL BUILDINGS AND WITH THE NBSLD (NBSFAST) COMPUTER PROGRAM

A. Comparison with Utility Residential Load Surveys

As mentioned earlier, there is good agreement between the available field data and TWOZONE calculations. These comparisons are summarized in Table 1.

TWOZONE predicts (line A1) that the yearly heating bill for an uninsulated 1450-ft^2 Oakland house should be 1122 therms (with a degree-day correction factor because of the colder than normal year on our Oakland weather tape). Pacific Gas and Electric, in their Residential Gas Load Survey, measured 1037 therms for a 1200-ft^2 uninsulated house in the Bay Area. After correcting for square feet, we find TWOZONE's predictions to be 6% lower than Pacific Gas and Electric's measurement.

For electrically heated, fully insulated houses in northern California (line B1) Pacific Gas and Electric's measurement of 10,270 kWh for the Sierra foothills compares favorably with the value of 10,000 kWh calculated by TWOZONE for Travis weather. For partially insulated single family houses using electric heat (R-11 ceiling, R-7 walls) TWOZONE predicted 6500 kWh (an average of 7000 kWh for Burbank and 6000 kWh for Los Angeles) in southern California; the Southern California Edison Company's measured values were 6400 kWh. The TWOZONE value for insulated apartments in southern California was 2225 kWh (averaging 2300 kWh for Burbank and 2150 kWh for Los Angeles); the Southern California Edison Company measured 2380 kWh.

The average energy savings by retrofit ceiling insulation to an existing single-family home in the Bay Area is 25% according to PG&E. The TWOZONE calculation gives a 31% reduction in the furnace loads, which would result in a 28% savings if we subtract the 10% of heating energy used by the pilot light.

B. Comparison with NBSLD (NBSFAST) Computer Program

The full details of the comparison of TWOZONE with NBSLD (NBSFAST) form the subject of a separate report.* Here we shall briefly outline the comparison procedure and show some typical results.

TWOZONE and NBSLD (NBSFAST) have some inherent and irreconcilable differences, mainly in the way they treat radiation between internal surfaces. NBSFAST cannot adequately handle internal walls and furnishings and hence consistently underestimates the radiation fluxes. TWOZONE does not evaluate inside surface temperatures by a detailed radiation balance calculation and hence consistently overestimates the radiation fluxes. As a result NBSFAST gives consistently lower furnace loads (by approximately

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*A. Gadgil and R. Kammerud, in preparation.

30%) than TWOZONE. Also, NBSFAST (and even NBSLD) has to be "tuned" with an appropriate heat capacity to realistically model any building.[5] Various strategies were used to make "reasonable" comparisons between these two programs under these conditions.

An identical house was modeled both with TWOZONE and with NBSFAST. The following dynamic tests compared the behavior of the two models under different, mutually independent environmental variations. Since TWOZONE and NBSFAST treat radiation in very different ways, tests 1 and 2 (see below) were conducted first "at night," and then with a noontime sun shining from a fixed location in the sky.

1a. Holding all other parameters constant, and with no solar insolation, an external temperature step is applied. The load response is independent of built-in TWOZONE time constants and provides a semi-absolute comparison of the two programs.

1b. Same test as (1a) but with the sun fixed at 12 noon position in the sky.

2a. Holding all other parameters constant and with no solar insolation, the thermostat is set back to less than the external temperature. The resulting load pull-down rate is dependent on the associated TWOZONE lumped internal mass assumption.

2b. Same test as (2a), but with the sun fixed at 12 noon position in the sky.

3. Holding all other parameters constant, the sun is switched on. The load response is directly dependent on the associated TWOZONE solar response time constant.

The results from tests (1a) and (2a) are shown here as samples.

Figure 3 shows the time response of the furnace loads in the two models in test (1a). The furnace load of the TWOZONE model takes 2.0 hr to cover 63% of the steady-state difference between the initial and final furnace loads. To reach a corresponding change, the NBSLD (NBSFAST) model takes 1.9 hr.

The results of test (2a) above are shown in Fig. 4. The "decay times" (time required to cover (1 - 1/e) = 63% of the steady-state difference) for the furnace load and inside air temperature are shown in Table 2.

There is a good agreement in the general shapes of the decay curves and also in decay times. The furnace load of the NBSLD (NBSFAST) model is consistently lower (by about 30%) than the furnace-load of the TWOZONE model. A major part of this difference is due to the absence of proper handling of surface-temperatures of internal partitioning in both models.*

C. Sensitivity to Lumped Heat Capacity

Since NBSLD (NBSFAST) itself needs to be "tuned" with a parametrized model for internal heat capacity, it cannot validate the magnitude of the internal heat capacity used in TWOZONE. However, the annual fuel consumption of a TWOZONE house is found to be quite insensitive to the lumped heat capacity used in the model. For example, for an uninsulated house in Oakland, the annual fuel consumption changes by 0.75%/(1000 Btu/$^{\circ}$F) over a range of ±1000 Btu/$^{\circ}$F about the value of 3200 Btu/$^{\circ}$F which we have commonly used.

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* The inside surface temperatures of external walls and the radiation losses from windows depend on the inside radiation temperature. Absence of internal walls and furnishings in the NBSLD (NBSFAST) model results in lowered radiation temperature due to weakened coupling between the inside air temperature and the inside radiation temperature. This contributes to the lower furnace loads.

IV. PRELIMINARY RESULTS ON SOME CONSERVATION MEASURES

Three studies--A, B, and C--are discussed below. Studies A and B were made using a very early version of TWOZONE. Study C was done with an intermediate version of TWOZONE which improved on the early version by the addition of the following: 5% interior shading at the windows; a 3-hr weighted time delay for contribution to the heating and cooling loads from sunlight incident through the glazing; wood framing corrections for thermal response of walls and ceilings; internal heat load schedule (people, lights, appliances); and floor losses. In addition, the house is currently shaded by similar houses on the east and west with an approximate 30° angle of obstruction. There is little shading on the south and north sides because of the assumed presence of a street on the south side, and a larger setback for a neighboring house to the north. There is a "tree" in the backyard on the north side.

A. Effect on Annual Energy Usage of Varying the Glass Area and Location[1]

For the study we assumed a residential model with glass areas that were 20% of the area of the walls, standard frame walls with 2 in. of insulation, a roof/ceiling with 2 in. of insulation, a north-south orientation, nightly thermostat setbacks to 60°F from daytime settings of 68°F, and a value of overall heat capacity corresponding to a 4-hr exponential relaxation time for inside air temperature.* The percentage of glass and its location were varied to determine their effect on the

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* The walls and the roof are described in detail in the ASHRAE Handbook (1972). Walls are from page 427, wall No. 37. The roof is from page 419, roof No. 21. The 4-hr exponential relaxation time is representative of the relaxation times observed in an informal survey of several Bay Area houses.

yearly heating bill. Also, the effect of single versus double glazing was studied. The results are shown in Fig. 5 for a residence and for a small commercial building.

Figure 5(a) shows the yearly residential heating fuel bill with moderate temperature setback in three climates for variations in south glazing. In Fig. 5(b), the yearly fuel use for a small commercial building with severe thermostat setback (nightly temperatures of 38°F as shown in Fig. 2) is plotted for variations in south glazing. Again, this is done for three climates.*

The conclusions are:

1. The addition of south glass does not have a significant effect on the yearly fuel use for houses in warm climates using night thermostat setbacks,
2. Double glazing is not cost-effective for mild climates with continued availability of fuel at the present prices.
3. The pay-back time for double glazing depends not only on the climate but also on the actual glass area in the building.

Figures 6(a) and (b) are presented as illustrations of the effect of sunlight on the inside temperature of a house when the furnace is kept off by setting the thermostat at 40°F. In Fig. 6(a), the house has either 40% or 20% single glazing on all walls and behaves somewhat as a greenhouse. In Fig. 6(b), the house has no glass on any wall and behaves like a windowless box. Note the increase in inside temperatures as windows are added, even though the windows are not concentrated on the south.

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*In the conclusions regarding commercial buildings, the special tax rebates, etc., for fuel and insulation expenses have not been taken into account.

B. Effect on Residential Fuel Use of Thermostat and Window Management

Nightly Thermostat Setbacks (11 P.M. to 7 A.M.)

A nightly thermostat setback of 10°F will result in a 10% to 25% saving in the yearly residential heating bill. For the same house, but in various climates, the absolute value of the fuel savings should be approximately the same.

For commercial buildings, large thermostat setbacks can result in dramatic savings. TWOZONE predicts 40-50% savings for a commercial structure with setbacks to 50°F during nights and weekends. This calculation agrees quite well with the metered results of the setback schedule at Sandia Laboratories.[6].

Some TWOZONE calculations for the effect of setback are given in Table 3. The following results are shown: (1) the percentage savings in fuel due to nightly thermostat setbacks in residential buildings are strikingly higher in the moderate climate (18%) than in the colder climate (11%); and (2) for commercial buildings, we can allow more severe thermostat setbacks at night with the result, for example, that a setback to 50°F again yields a greater percentage savings in moderate climates (45%) than in colder climates (38%).

These differences in percentage savings result from the furnace being completely shut off for several more night hours in moderate climates, even in the case of the moderate thermostat setbacks. However, in the case of a very severe setback (to 37°F), the savings for both cold and moderate climates become equal (46%).

Window Management

Reflective film on windows reduces summer heat, glare, and fading of furnishings, but if applied permanently the film also reduces useful solar heat gain during the winter; half of the summer savings are offset by winter losses. The recommendation is that the reflective film not be applied permanently, but rather as a roller shade, a venetian blind, or as a dual mode interior storm window. Then during the winter there is solar heat gain during the day and also better insulated windows at night (if the shade or blind is confined to a tight track). Table 4 summarizes the effects of various window management strategies.

Summer electricity savings yield a 20-30% annual return on investment in reflective film. Even more important, however, is the saving in peak-power. On an otherwise unshaded window on a clear summer afternoon, each square foot of film saves 10 W of electric power in air conditioning. To supply new peak capacity the utility must invest at least 50¢/W. So by investing $\$1/\text{ft}^2$ of window area the homeowner can save the utility an investment of $5. When residential time-of-day electric pricing is introduced, it will greatly add to the incentive for summer shading.

C. Effectiveness of Various Retrofit Measures

The following retrofit measures (on an existing home) were considered: thermostat timers, ceiling insulation, wall insulation, and storm windows. We have preliminary results for two locations: Oakland, California (3000°-day) and New York City (5000°-day). In Fig. 7 the furnace output has been apportioned to show the energy used to offset air infiltration and losses through the floor, windows, walls, and ceiling.

Oakland. A summary of the Oakland results is presented in Figs. 7(a) and 7(b). The typical Oakland house is taken to be a single-level, uninsulated, 1450-ft^2 house with 20% of the wall area made up of single-pane glass. In making the calculations, a cost of \$0.33/therm of furnace output is used (\$0.20/therm of natural gas divided by 60% furnace efficiency)[7]. The following retrofit costs were assumed :

Addition of R-19 insulation to ceilings	25¢/ft^2
Addition of R-11 insulation to walls	50¢/ft^2
Addition of storm windows	\$2/ft^2

From Fig. 7(a) we see that:

1. Simply lowering the thermostat decreases the fuel bill by 6% per degree,
2. Adding R-19 ceiling insulation decreases the fuel bill by \$90; for an installation cost of \$360 this gives a 25% annual return or a pay-back time of 4 yr.
3. Adding R-11 wall insulation gives a 14% return or a pay-back time of about 7 yr.
4. The installation of storm windows gives an annual return of 7% or a pay-back time of over 14 yr.
5. A further reduction in the heating bill can be attained by nightly thermostat setbacks, of say 10°F, from 70° to 60°, at bedtime until 30 min before waking up the next morning.

Alternatively, in terms of cost effectiveness, one might choose nighttime thermostat setbacks as the first measure to be instituted; this is illustrated in Fig. 7(b). A nightly setback of 10°F reduces the fuel bill by approximately 25%. The installed cost for an automatic thermostat timer is \$100 but the annual return on this investment is 75%. Looking at the rest of the graph, we see that the installation of ceiling and wall insulation is still cost-effective with returns of 19% and 11%, respectively, whereas storm windows give only a 4% return.

In these considerations we have so far not considered caulking. Using pressurized cans of polyurethane foam, the infiltration can be reduced by about 30% by putting foam around windows and sole-plates. The cost is assumed to be about \$50 (labor donated by homeowners) for a 1500-ft^2 house. This will yield a return on investment of 10% to 25% (depending on the amount of existing insulation) in a Oakland house. The usual caulking, available in tubes, is 4 to 12 times more expensive and will reduce the return on investment accordingly.

In summary, the recommended retrofit measures for Oakland are repairs and caulking, clock thermostats, ceiling insulation, and wall insulation. (Currently there is considerable debate over the actual effectiveness of blown-in wall insulation; in our calculations we assume that the insulation can do what the contractors claim.) Storm windows are marginally cost-effective for Oakland.

It should be noted that in apportioning the furnace load, we observe decreases in each individual heat-load even though a retrofit measure is applied to just one of them. The explanation is as follows: For each individual load, L(I), we plot

$$L'(I) = L(I) \times \%(\text{furnace}) \qquad (1)$$

where

$$\%(\text{furnace}) = \text{furnace load}/(\text{furnace load} + \text{solar heat gain through glass} + \text{internal heat}) \quad (2)$$

If a retrofit measure is instituted, the overall furnace load decreases (the furnace is off more hours per day) and hence the %(furnace) decreases (see eqn. (2)). Thus, each of the other loads decreases too. That is, part of the solar input and internal heat input is shifted to cancel other losses.

For example, in Figs. 7(a) and 7(b), as illustrated by the triangular cross-hatched areas, the "windows, floor, and infiltration" part of the furnace load decreases by 20% as ceiling insulation and wall insulation are added.

New York City. A summary of the New York City results is presented in Figs. 8(a) and 8(b). The typical New York City house is assumed to be the same as the Oakland house with one important exception: the walls and ceiling already have 2 in. of insulation (equivalent to a value of R7). Hence, the fuel savings are significant, but not large. The high cost of fuel, however, makes many of the retrofit measures very cost effective. In making the New York calculations, a cost of $0.55/therm of furnace output is used ($0.30/therm of fuel oil divided by 55% efficiency). In summary, the recommended retrofit measures for New York City are caulking, clock thermostats, storm windows, and the addition of R-19 insulation in the ceiling.

In New York, foam caulking around windows and under the sole-plate yields a return on investment of about 60%. Again, usual caulking is more expensive by a factor of 4 to 12, and reduces the return on investment accordingly.

Because the furnace is on more of the time in New York than in Oakland, the coupling between various loads is less striking for New York. Thus for Oakland, in Fig. 7(a) we have displayed a triangle representing a 20% decrease in the window-floor-infiltration load when the ceiling and walls were insulated; in Fig. 8(a) for New York, this triangle is only 7% high.

V. CONCLUSIONS

Use of the computer program TWOZONE to calculate heating and cooling loads on single family residences has been briefly discussed. Results from TWOZONE agree well with the available field data and with NBSLD (NBSFAST) computer program. Using TWOZONE, we have shown that there is an optimum glass area and location, depending on the climate, in designing houses. The effects of various thermostat and window management strategies in two different climates are presented; the annual furnace load is apportioned into component loads; and the effectiveness of various retrofit measures on existing buildings in two different climates is evaluated in terms of their cost and the fuel saved.

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2. Subroutine Algorithms for Heating and Cooling Loads to Determine Building Energy Requirements, Energy Calculations 1, ASHRAE, 1975.
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TABLE 1

Comparison of utility residential load surveys with TWOZONE calculations. The gas-heated homes were uninsulated; the electrically heated homes were at least partially insulated.

	Measured	Calculated
A. Gas heating in therms, uninsulated		
1. PG&E (Bay Area)	1,194[a]	1,122[b]
B. Electric heat, insulated (kWh)		
1. PG&E (N. Calif.)	10,270[c]	10,000[d]
2. SCE, home (Los Angeles)	6,400[e]	6,500[f]
3. SCE, apartment	2,380[g]	2,225[h]
C. Energy savings by retrofit Ceiling insulation PG&E, Bay Area	25%	27-30%

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[a] Corrected for size: Actual measurements were 1037 therms (avg.) for 1200 ft^2 (avg.) houses in Bay Area. Data collected by PG&E in 1967 and 1968 with sub-metered houses at Pinole. No details of the range of spread of data available.

[b] Calculation was made with 1955 Oakland weather tape. 1955 was unusually cold, 3975 DD, instead of NOAA average of 2910. Actual calculation was 1533 therms. Scaling by DD, we find 1122 therms.

[c] PG&E measurements of 67 electrically heated houses in Sierra Foothills from Sept. 1965 to Aug. 1966. Average floor area was 1451 ft^2, average

annual load was 10,270 kWh, with a spread of about 2,500 kWh on each side.

[d] Calculation for full insulation (R-19 ceiling, R-11 walls), Travis AFB Weather.

[e] SCE (Load Research Dept.) measurements of sub-metered electrically heated single family homes, 1968.

[f] Calculation for partially insulated (R-11 ceiling, R-7 walls) house, average of Burbank and Los Angeles weather.

[g] SCE (Load Research Dept.) measurements of electrically heated apartments, 1968.

[h] Calculations for full insulation, average for Burbank and Los Angeles weather.

TABLE 2.

Comparisons of decay times[a] for NBSLD (NBSFAST) and TWOZONE models of "the same" house during a temperature pull-down test.

	Decay time for furnace load	Decay time for inside air temperature
NBSLD (NBSFAST)	2.4 hr	3.9 hr
TWOZONE	2.2 hr	4.0 hr

[a] Decay time is the time required to cover (1-1/e) = 63% of the difference between steady state values of the relevant variable.

TABLE 3

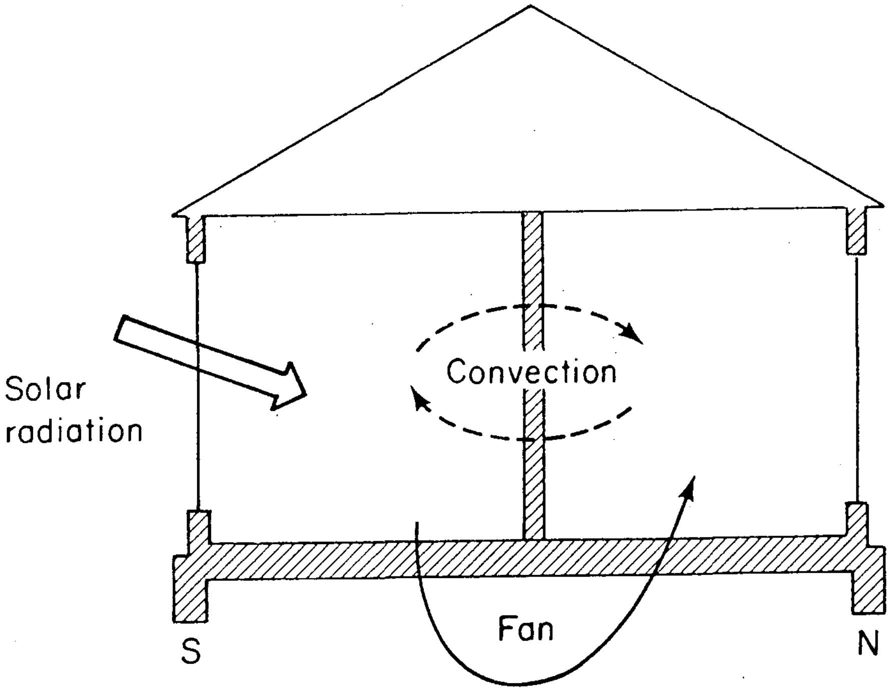
Fuel savings for several thermostat setback levels in a 1600-ft^2 residential or commercial space. The space is assumed to have 20% glass area in each wall, single-glazing, and a base daily daytime temperature of 68°F. Travis Air Force Base is halfway between San Francisco and Sacramento, and is chosen to represent northern Calfornia.

Temperature setback schedule	Winter fuel requirement			
	Washington, D.C.		Travis AFB, CA.	
	4650 deg-day		2600 deg-day	
	(therms)	(%)	(therms)	(%)
Residential:				
No setback	812	100	510	100
Night setback to 60°F	720	89	420	82
Commercial:				
No setback	378	100	240	100
Night/weekend setback to 50°F	235	62	132	55
Night/weekend setback to 37°F	206	54	129	54

TABLE 4.

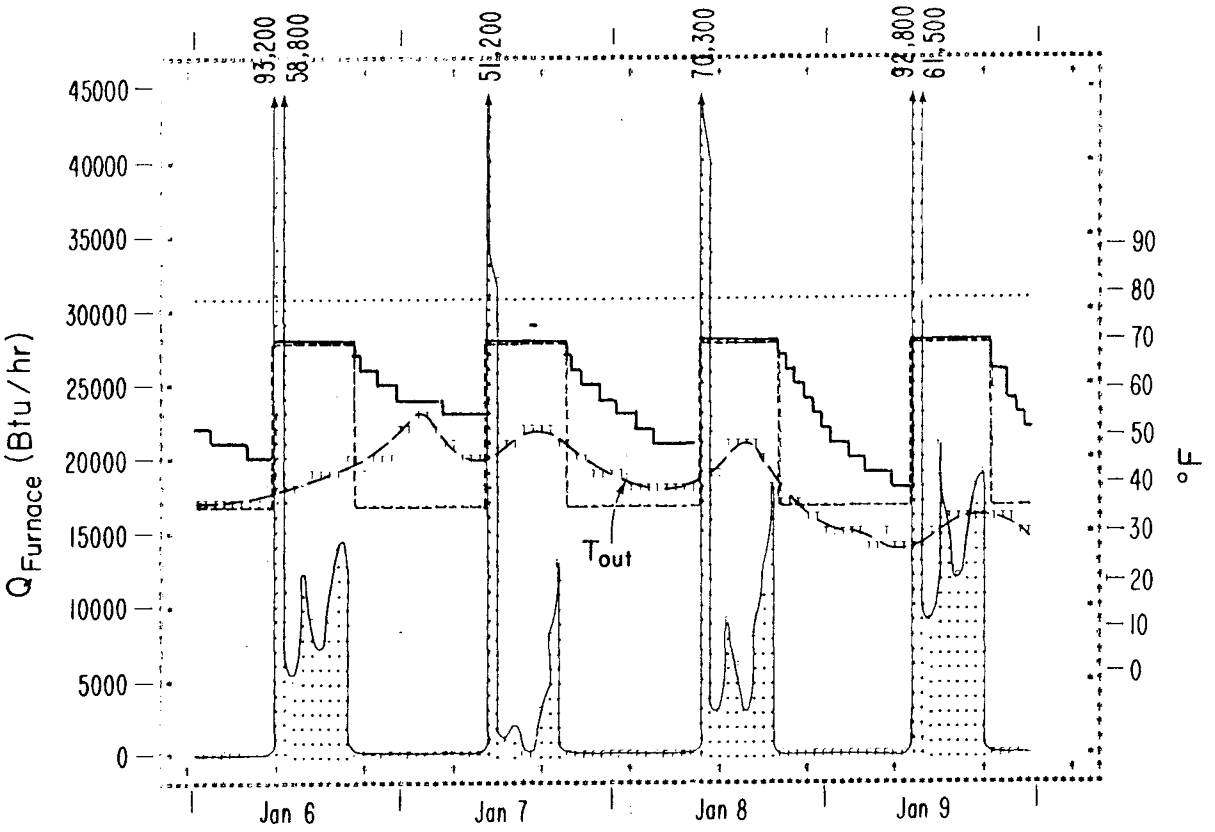
Winter fuel consumption for various window-management strategies. Calculations for a single-glazed Washington, D.C. house, with 20% window area in each wall. The reflective film is assumed to be P-18 Scotchtint with a shading coefficient of 24%. In the summer the Scotchtint saves about 1500 ton hours of air conditioning ($75 electric savings).

	U-value (Btu/hr-ft^2-^{o}F)	Winter fuel	
		(therms)	(%)
Permanent Film, S.C. = 24%	0.935	800	114
Clear single-glazing	1.1	700	100
Roller shades:			
Closed 11 P.M. - 7 A.M.	0.51	650	93
Closed 5 P.M. - 7 A.M.	0.51	620	89
Double-glazing	0.65	590	84



XBL 7610 4299

Fig. 1. Residential two-zone model, showing north and south halves of house connected only by air forced by the furnace fan, or by convection. Most of the results of this paper assume that a 750-cfm furnace fan operates continuously. In a real house this would be accomplished by an extra thermostat in a south room. At temperatures above 72°F, the thermostat would turn on the fan without turning on the furnace.



XBL 7611-4349

Fig. 2. Hourly temperatures and furnace output for a school (light construction) with night thermostat setback to 35°F. Outdoor dry bulb temperature is printed as a "T," thermostat setting as a "-," and inside temperature as a solid line. Hourly heat required to maintain the thermostat setting is a column of dots, so the daily furnace output is proportional to the dotted area. The daily spikes on the printout are caused by the furnace load going off-scale when the thermostat setting is increased each morning. (Washington, D.C., 1962 weather.)

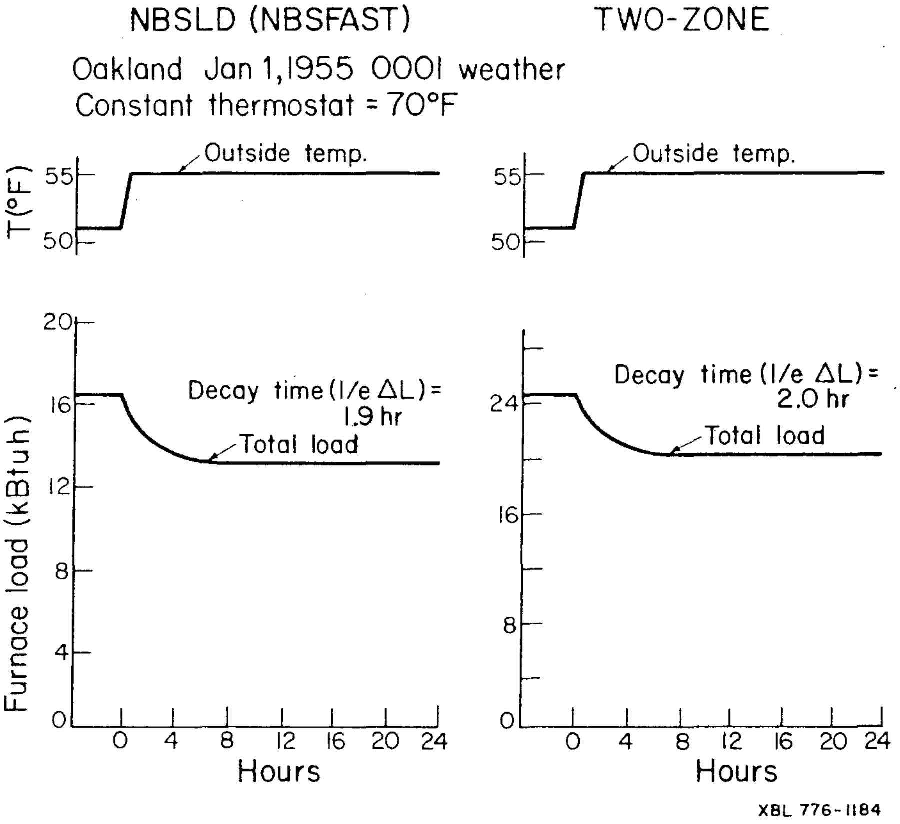
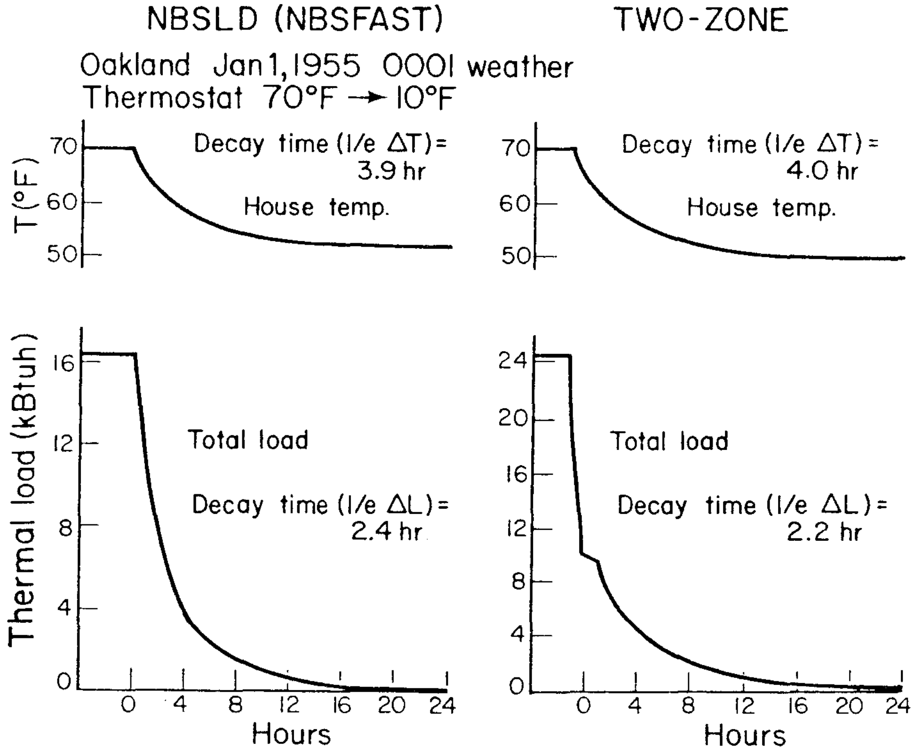
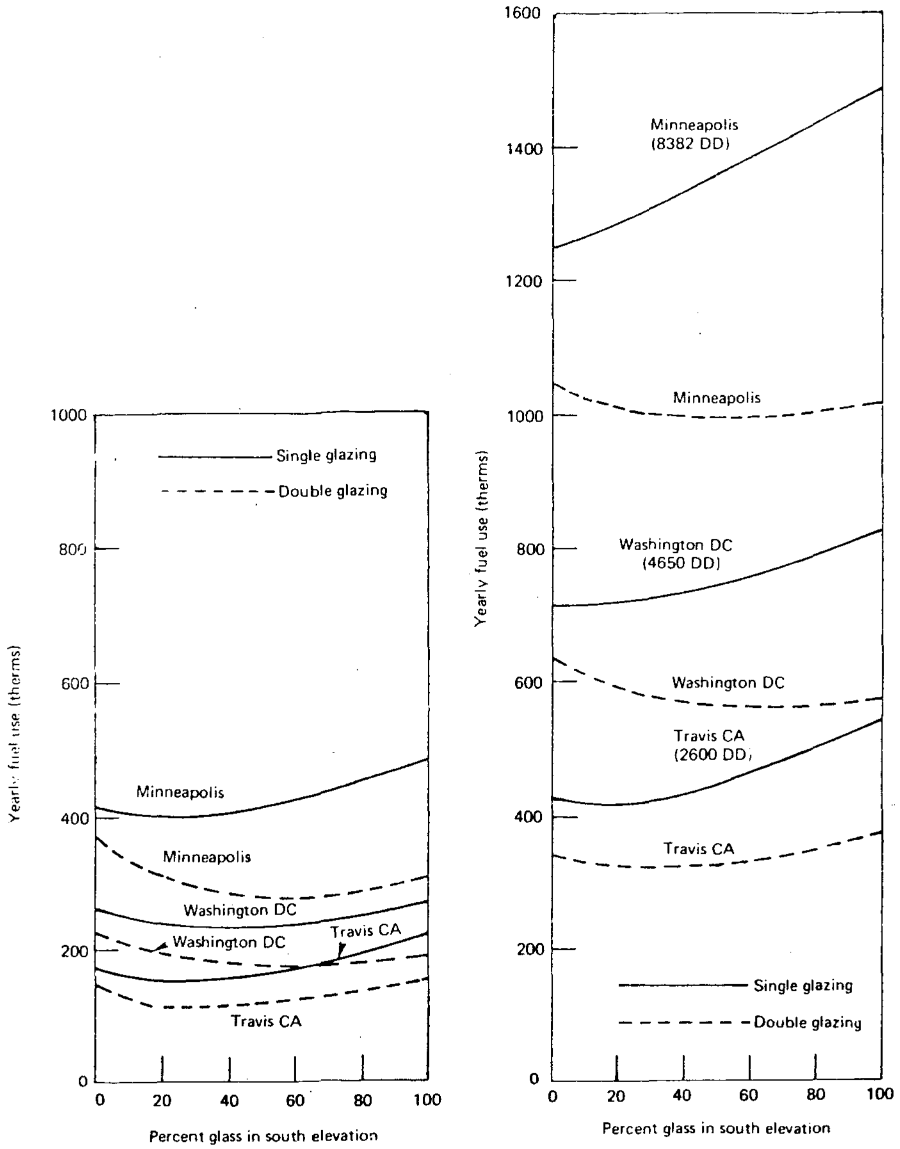


Fig. 3. Comparison of loads calculated by NBSLD (NBSFAST) and TWOZONE when a step is applied to the outside air temperature. The load shapes agree, but the absolute value cannot, mainly because NBSFAST has no internal partition (see text). The house is uninsulated.



XBL 776-1183

Fig. 4. Comparison of temperatures and loads as calculated by NBSLD (NBSFAST) and TWOZONE when furnace is shut off. As in Fig. 3, shapes agree but absolute loads cannot. Because lumped heat capacity "C(air)" is 3200 Btu/°F in TWOZONE, and is scaled proportional to steady-state loads for NBSFAST, it is scaled to 2100 Btu/°F. The house is uninsulated. The discontinuities in the TWO-ZONE load curve arise because the program's smallest step is one hour. For the first hour the small internal heat capacity cools rapidly by conduction through the windows and by infiltration; later on we see the inside of the walls cooling more slowly by conduction to the outside of the walls and via contact with the inside heat capacity, which still cools via the windows and infiltration.



XBL 7512-10093A

Fig. 5. Sensitivity of fuel use to percentage of south glazing: (a) for a residence, with night thermostat setback to 60°F; (b) for the lightweight commercial building of Fig. 2, with setback to 38°F. Both figures are from Ref. 1.

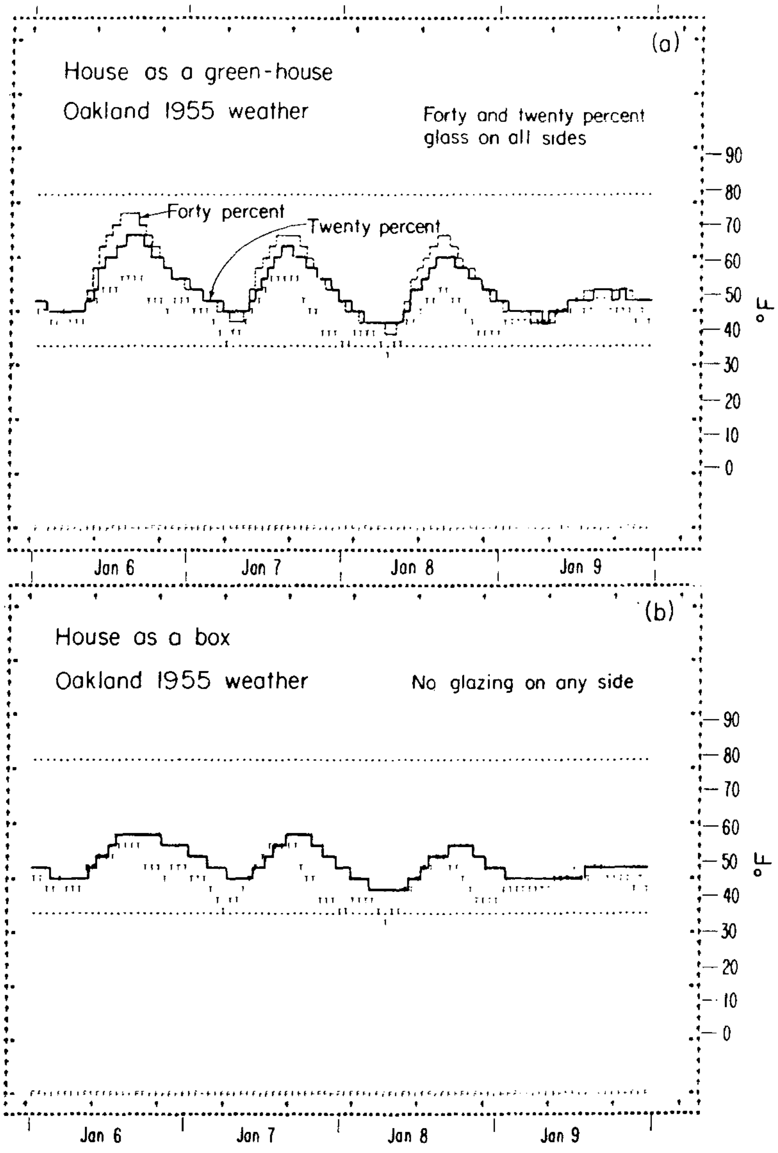


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Fig. 6. The house as a greenhouse, and as a windowless box. A 1955 Oakland weather tape was used. The house is uninsulated. (a) Glazing 40% and 20%, single glazed, all around. (b) Glazing is reduced to 0%; solar heat gain still heats the house by raising the "solair" temperature of the outside of the walls and roof.

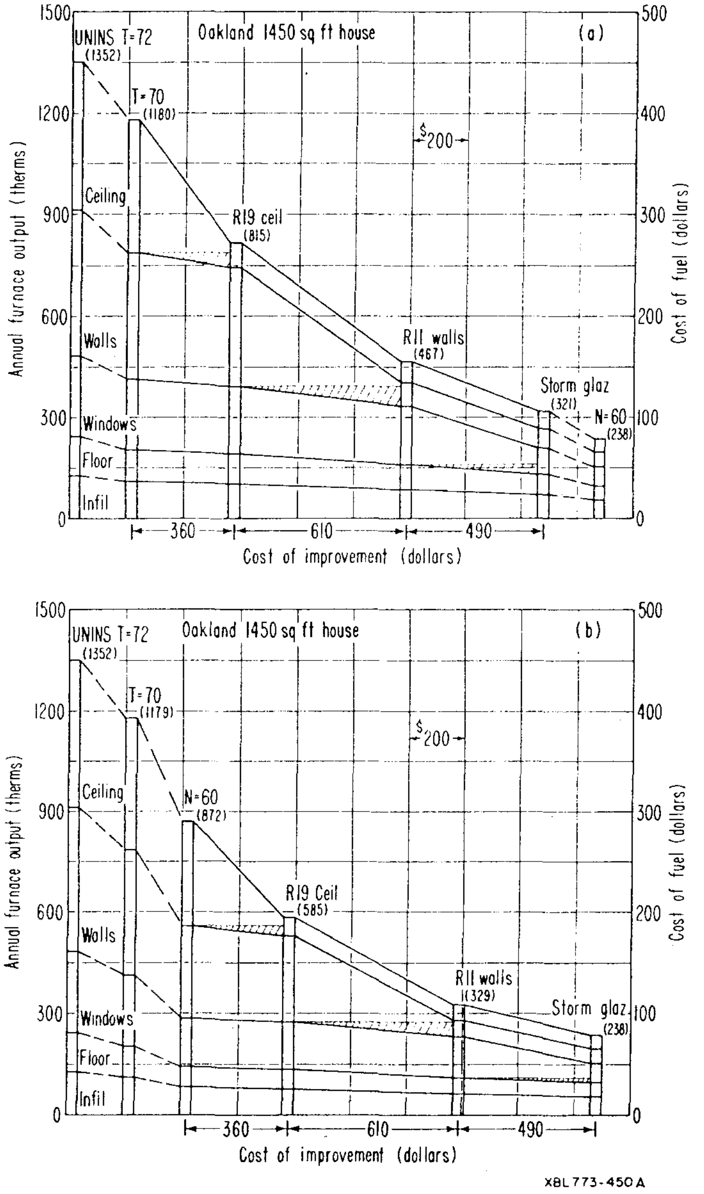

Fig. 7. Savings possible by thermostat setback or conservation retrofit measures on an uninsulated Oakland house, calculated using a 1955 weather tape. Costs for fuel and retrofit measures and apportioning of loads, are discussed in the text.
Both Figs. 7(a) and (b) start at the left with a bar representing a "pre-embargo" house kept at 72°F day and night, followed by a more "recent" house kept at 70°F. However, in Fig. 7(a), no night thermostat setback is assumed until the last bar; instead, insulation and storm windows are retrofit in sequence. In Fig. 7(b) a night thermostat setback to 60°F (N = 60°) is assumed at the third bar; the retrofit measures come last because they are less cost-effective. Both plots end at the same bar, representing all conservation measures including night setback, and furnace output down to 238 therms. The dollar cost scale at the right is based on a gas price of 20¢/therm divided by a furnace efficiency of 0.6 or a cost of 33¢ per therm of furnace output.

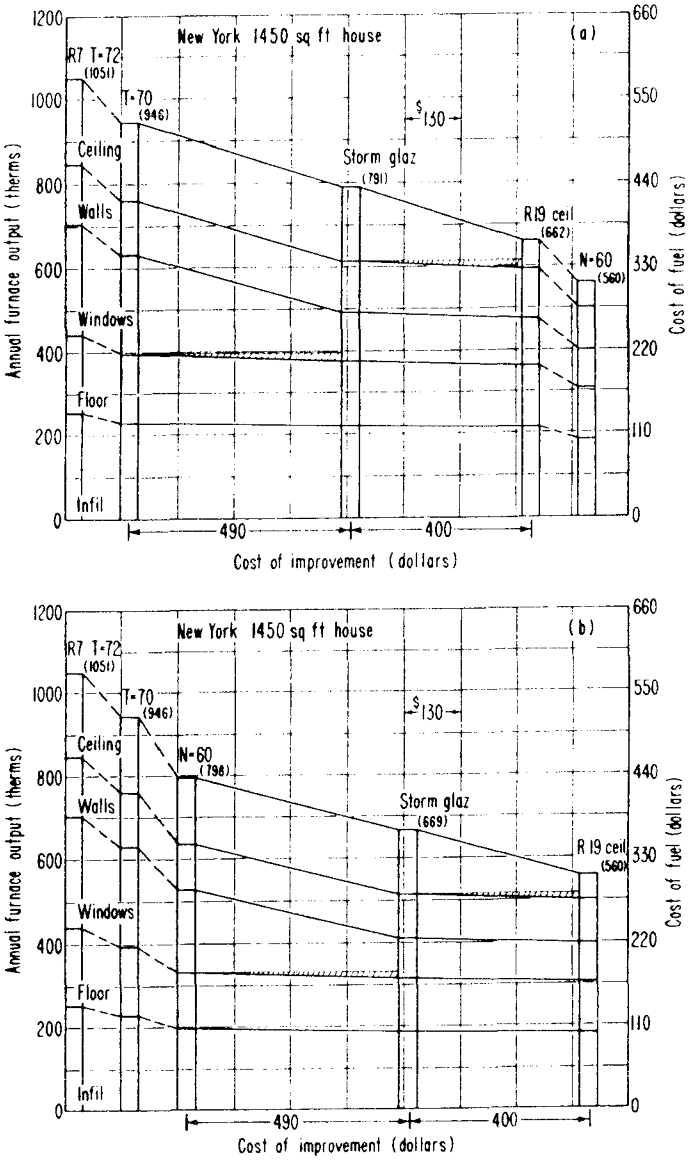

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Fig. 8. This figure is the same as Fig. 7 except that the house is a partially insulated New York house and the weather tape was for 1951 New York City weather. New York fuel oil is priced at 30¢/therm of oil (40¢/gallon). This yields 55¢ per therm of furnace output (see text).