### Title
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# Electric Co-heating: A Method for Evaluating Seasonal Heating Efficiencies and Heat Loss Rates in Dwellings

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## DISCLAIMER

# ELECTRIC CO-HEATING A METHOD FOR EVALUATING SEASONAL HEATING EFFICIENCIES AND HEAT LOSS RATES IN DWELLINGS

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## Abstract

An experimental technique called electric co-heating is presented. Portable electric heaters distributed throughout the dwelling to be tested are operated overnight at the same time as the regular heating system. Cross-correlation with outside temperature data collected several times per hour allows the separate determination of heating efficiency, fireplace performance and overall building heat loss coefficient.

In this paper, electric co-heating is applied to measure the net efficiency of a forced-air gas furnace and a fireplace in a house located in the San Francisco Bay Area. Preliminary tests conducted in mild weather indicate a net efficiency of 53% for the heating system and less than 5% for the fireplace.

## Introduction

Most available information on determining heating efficiency is of a semi-theoretical nature: individual losses such as stack gas outflow, cycling operation, duct heat loss and duct leakage are analytically modeled and their effects combined. The resulting charts require information such as flue gas temperature and $CO_2$ content, oversizing factor and climatic data [1,2,3]. Some methods do not include the effect of distribution losses, which have been found to account for up to 40% in actual tests if the uninsulated air ducts lead through unheated spaces [4].

Building envelope performance is modeled on a component by component basis, addressing walls, windows, attic, ground losses and air infiltration. Numerous analytical and numerical methods exist that calculate the cumulative heat transfer through the envelope at given indoor and outdoor conditions [5,6].

The quantitative effects of energy-saving measures addressing the building envelope or the heating system can be calculated by such methods, but the experimental verification is difficult. The task is complicated by the pronounced house-to-house diversity recognized in studies of large samples of dwellings, that is not amenable to modeling [7,8].

Correlation of the data contained in utility bills with degree-days yields only aggregate results that do not distinguish between heating efficiency and envelope performance. If a house is found to have high energy use in relation to its floor area and the prevailing weather, we don't know whether its walls are poorly insulated, whether it is very leaky or whether its net heating efficiency is low. Furthermore, utility bills have to be collected over several months in order to accumulate sufficient data, which impairs prompt feedback on the effectiveness of individual energy-saving measures.

To resolve experimentally the individual contributions from envelope performance, leakage characteristics and heating efficiency, inexpensive and practical *in-situ* diagnostic techniques are needed, such as pressurization, infrared scanning, thermal "decay" and "float", surface temperature and heat flow measurements and electric co-heating.

## The electric co-heating method

In this technique, the function of the heating system to be tested is temporarily assumed by portable, thermostated and metered electric heaters distributed throughout the house. Subsequently, the regular heating system is operated. The ensuing measured load reduction seen by the electric heaters indicates the net heat gain to the house; the *net* efficiency of the heating system is calculated by dividing the measured net heat gain by the measured energy consumed by the heating system.

It is important to emphasize that this method measures only that heat that actually benefits the living space. Therefore, leaky, uninsulated ducts will decrease net efficiency in the same fashion as a poorly tuned furnace. An earlier version of this method has been previously employed in a townhouse in New Jersey [11]. The main difference with respect to the present application is that electric co-heating was provided at a constant rate, while the indoor temperature was maintained constant by the house heating system through the action of the regular thermostat. In the present application the roles are exchanged: indoor temperature is maintained constant by electric co-heating while the furnace is cycled manually in a well defined, regular sequence. Thus, we avoid the possibility of inadvertently "averaging" over different heating efficiencies as we change the characteristics of the furnace cycle.

The electric co-heating method is currently in its development stage and the results described in this paper are to be considered an illustration of the method and its capabilities, not a definitive assessment of heating systems (or fireplaces).

A further capability of this method is the direct measurement of the overall heat loss coefficient (in W/K) of the house under investigation. If simultaneous air infiltration measurements are made, the contribution by heat transmission alone through the opaque envelope and the windows can be inferred. Measured values of net heating efficiency, heat transmission coefficient and air infiltration at standardized conditions (another LBL paper is being presented here on this subject) provide a promising set of values for the "energy signature" of a house. Such a signature could be used to estimate the actual energy consumption over an entire heating or cooling season.

Another application of electric co-heating is that of load localization: By individual metering and thermostatic control of the portable electric heaters, the contribution of each room to the overall heat loss can be determined and particularly lossy areas identified. This load localization capability will be described in connection with the fireplace tests: after ignition of a fire, the increase in air infiltrating through the outer envelope, measured by tracer gas techniques, was seen as an increase in electricity consumed by the electric heaters located in the outer rooms.

The net efficiency of cooling systems could also be tested with the electric co-heating method. Here, the increase (rather than the reduction) in electric heat needed to keep a constant indoor temperature indicates the net heat removal rate of the cooling system and, therefore, its net efficiency. This application has not yet been tested by LBL, but appears on the research agenda for the near future.

## Experimental setup

Our tests on furnace and fireplace heating efficiency using electric co-heating are currently in progress at an unoccupied ranch-style house in Walnut Creek, California. It is rented by LBL to develop energy performance standards and conservation strategies [9]. The three-bedroom, single-story house has 100 $m^2$ of floor area, an unheated crawl space, insulated walls and attic and single-glazed windows. Heating and cooling are provided by a central forced-air system, with the supply ducts in the crawl space and the return duct in the attic. A 23.4 $kW_t$ natural gas furnace is located in a closet vented to the crawl space, but isolated from the room air. A masonry fireplace is set into the outer living room wall, with an exposed brick chimney. The floor plan of the house is shown in Fig. 1.

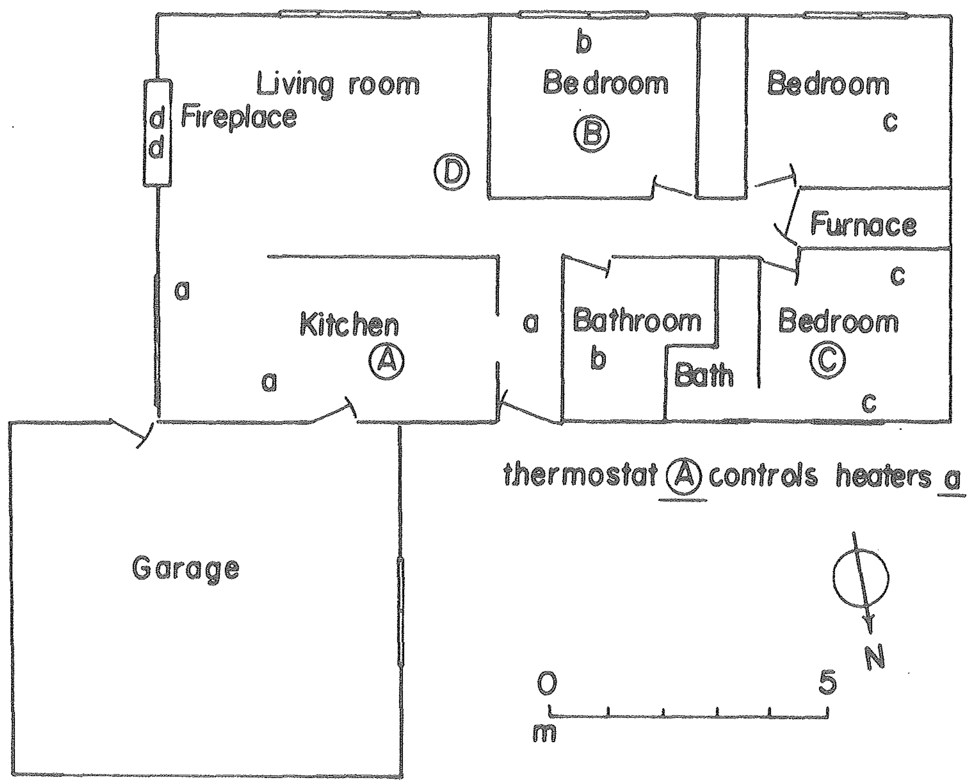


Figure 1. Floor plan of research house with location of heaters and thermostats.

Also shown are approximate locations of the portable convective heaters with capacities ranging between 0.3 and 1.3 kW, and the thermostats by which they are controlled. Wherever possible, the heaters are placed in the air stream leaving the floor registers. In the living room we use radiant instead of convective heaters (with a capacity of 3.6 kW) to mimic the radiant heat gain from the fireplace when it is tested. The air temperature is monitored with ADC590k solid state temperature sensors located at 20 different points through the dwelling and outdoors. The electric power of the heaters is measured separately by four General Electric watthour meters (one for each thermostat) as well as by the house meter, which also registers any other useful electric power, such as the heat generated by lights and by the refrigerator.

Air infiltration is monitored continuously with a controlled-flow tracer gas technique: Ethane is injected at a constant rate into the house at four different locations and the concentration measured in the return duct with a Wilks Miran 101 infrared analyzer [10]. The volumetric air infiltration rate is calculated from the equation

$$R = \frac{F}{C} - \frac{(dC/dt)}{C}V \tag{1}$$

| | |
|---|---|
| R | is the volumetric air infiltration rate ($m^3$/hr); |
| F | is the flow of injected ethane (cc/hr); |
| C | is the measured ethane concentration (ppm); |
| dC/dt | is the time derivative of the ethane concentration (ppm/hr), averaged over at least 10 minutes; |
| V | is the volume of the house ($m^3$). |

If needed, the number of air changes per hour can be calculated from the ratio R/V. Mixing of the tracer gas with room air is ensured by running the furnace blower continuously; typical measurement accuracies attainable with this method are 5-10%.

Discussion of a heating efficiency test

The efficiency of the gas-fired, forced-air heating system in our research house was measured in an as-is condition by electric co-heating. The most important variables are plotted in Fig. 2. The top figure shows the aggregate electric power consumed by the electric heaters and all other electrical equipment in the house. The power shows an increasing trend, related to the gradual drop in outdoor temperature and the slight increase in the air infiltration rate over the period of the run. Air infiltration is labelled as air changes per hour, but plotted in units of a heat loss rate, $Q_{AI}$ (watt), according to the equation:

$$Q_{AI} = R\rho c_p (T_{in} - T_{out}) \tag{2}$$

$\rho c_p$ is the volumetric heat capacity of air (Wh/$m^3$/$^oC$).

Measurements of electric power were averaged over 40 minutes, indicated by the length of the horizontal bars in the top Fig. 2. The air infiltration rate was averaged over the four time periods indicated: 1)

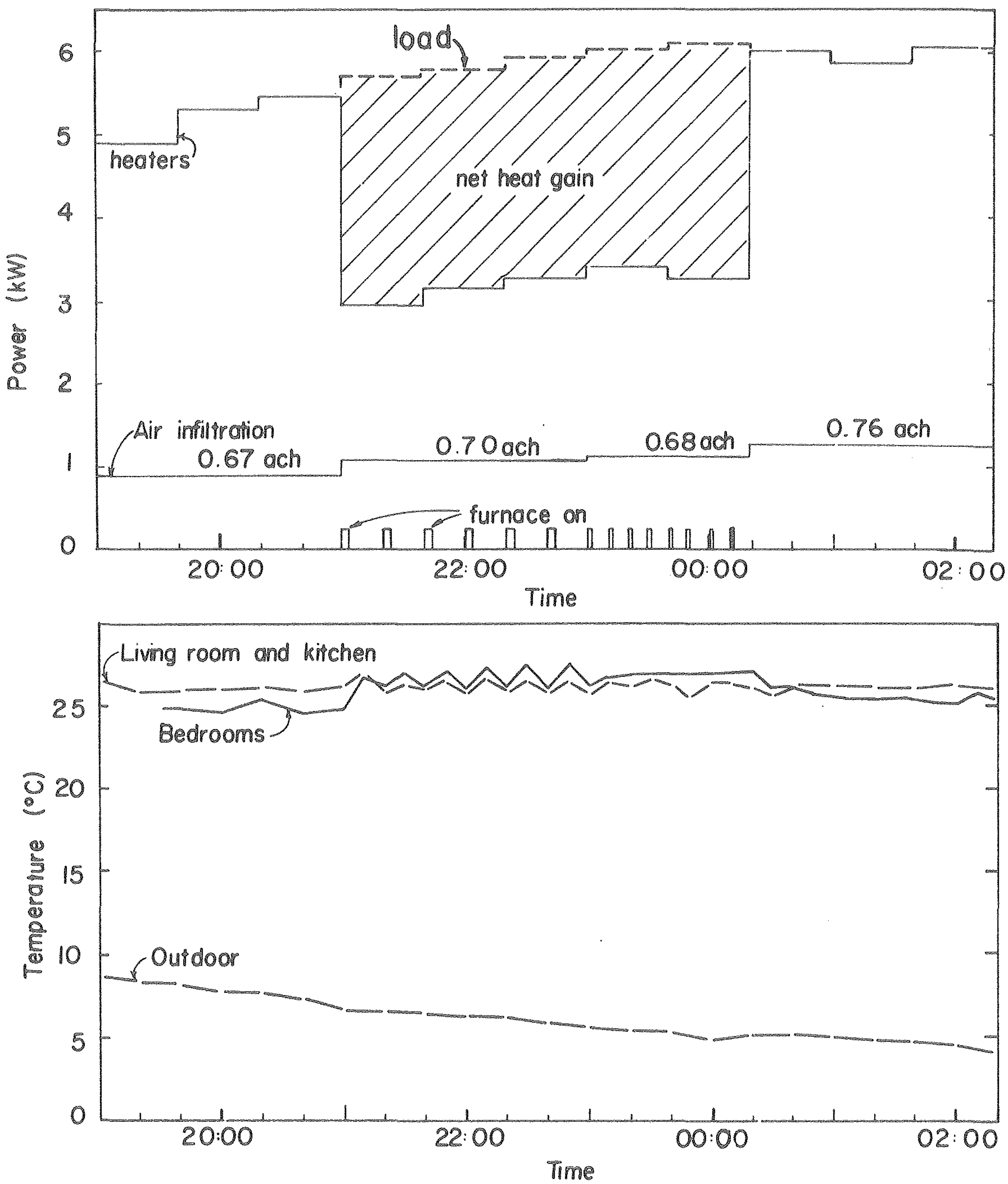


Figure 2. Electric heaters consumption, calculated heat load, air infiltration load, and temperatures during a furnace efficiency test.

electric heating only; 2) furnace cycling in a manually controlled mode (4 minutes on, 16 minutes off) with electric co-heating; 3) furnace cycling at the same duty cycle (20%), but with shorter on-times (2 minutes) and off-times (8 minutes); 4) resumption of electric heating alone.

The drop in electric power drawn by the heaters indicates the net heat gain from the heating system, when this was activated. The exact amount of the drop in electric power was calculated as follows: The net heating load for periods 1 and 4 was equated to the measured electric power. (We assumed that the loss of furnace blower heat through the ducts, estimated at about 300 W, roughly equaled the heat gain from the two researchers present.) By dividing the average heat loads for period 1 and 4 by the corresponding average indoor-outdoor temperature differences, an overall heat loss coefficient for the house can be determined: 297 W/K for period 1, 283 W/K for period 4. By subtracting the contribution of air infiltration, $R\rho c_p$, for the two periods, we obtain UA=245 W/K and UA=224 W/K, respectively, representing the overall losses by transmission alone. The 9% difference between the two values gives a sense of the accuracy of our method. A separate detailed heat load calculation, including walls, attic, floor, windows and doors yields UA=219 W/K. The dashed line in periods 2 and 3 represents the heat load calculated using actual temperature differences and the measured values for heat transmission and air leakage according to the formula:

$$Q_L = (UA + R\rho c_p)(T_{in} - T_{out}) \tag{3}$$

To estimate the load, we used UA=235 W/K, the arithmetic average of the UA values for periods 1 and 4. The small step increase in load for the middle periods with respect to the electric consumption in periods 1 and 4 is caused by the slightly higher indoor temperature during the middle periods, as can be seen in the bottom Fig. 2; this is a consequence of a slow control system; this will be corrected in the future.

The net heat gain from the heating system is evaluated from the difference between calculated heating load (dashed line) and measured electric power. The net heat gain in period 2 (on/off times = 4/16 minutes) is 2,667W, in period 3 (on/off times = 2/8 minutes) it is 2,749W. The average furnace fuel consumption rate, including pilot light, was 5,090W. Thus, the net efficiencies are 52.4% for period 2 and 54.0% for period 3. Both of these values are significantly below what one would predict with a pure stack loss method, that does not account for duct losses.

The 4% difference between the two efficiency values could be ascribed to the lower average duct temperature during short cycling (thus diminishing the duct heat loss), but it is doubtful that we can detect reliably such small effects with our method in its present experimental state. The purpose of this test was to demonstrate the feasibility of the method and to point to the importance of duct heat loss in depressing seasonal heating efficiency.

Future applications of the electric co-heating method wil measure seasonal efficiencies with varying duty cycle, length of on-time, blower operation strategy and duct insulation. At the time this test was done, about half of the ducts were insulated and taped. We are planning measurements 1) with all ducts uninsulated and untaped, 2) with the ducts taped, 3) with the ducts taped and insulated to an appropriate R-value. Leakage tests will be performed using the standard blower door technique.

## A brief review of fireplace performance

Few people realize that their quaint fireplace that barely heats one room may generate heat at a rate equal to or greater than the furnace that heats their whole house: In a mid-sized fire, the chemical energy of wood is converted into heat at a typical rate of about 30 kW! However, roughly 90% of the heat released by the burning wood escapes through the chimney, mostly in the form of hot gases. Only the remaining 10% is actually radiated to the living area. Moreover, large amounts of hot gases exhausted through the chimney cause additional infiltration into the dwelling, above and beyond the "natural" infiltration. Thus, the net efficiency of a fireplace operating in an actual house is usually less than 10%; for leaky houses in very cold climates, it can actually become negative! (In this context, we define net efficiency as the difference between the heat delivered to the house and the heat used to warm extra infiltrated air, divided by the higher heating value of the burned fuel.) An excellent review of the physics and most other aspects of fireplaces can be found in a book by J. Shelton and A. Shapiro [12].

In our tests we used gas burners since it is difficult to control and measure the rate of fuel consumption of a wood fire. We used four 15 cm diameter gas burners arrayed in a row about 0.7 m long, metered by a separate gas meter on the domestic gas supply. They produce a luminous flame which can provide heating rates up to 47 kW. Separate mesurements indicate, however, that a wood fire radiates proportionately more than natural gas. Thus, the efficiency figures presented in this paper may be lower than one would obtain using wood. We are currently developing radiation-enhanced gas burners to overcome this problem.

## Electric co-heating applied to fireplace efficiency measurements

The results of a typical six hour fireplace test are shown in Fig. 3. The run is divided in three periods: 1) before, 2) during, and 3) after fireplace operation. The damper was in a fully open position throughout. About 6 hours before beginning and throughout the entire run the house temperature was maintained constant by electric heating. All loads and electric consumptions are plotted in the form of 40 minute averages in the top Fig. 3.

As in the furnace run, an overall heat loss coefficient was computed

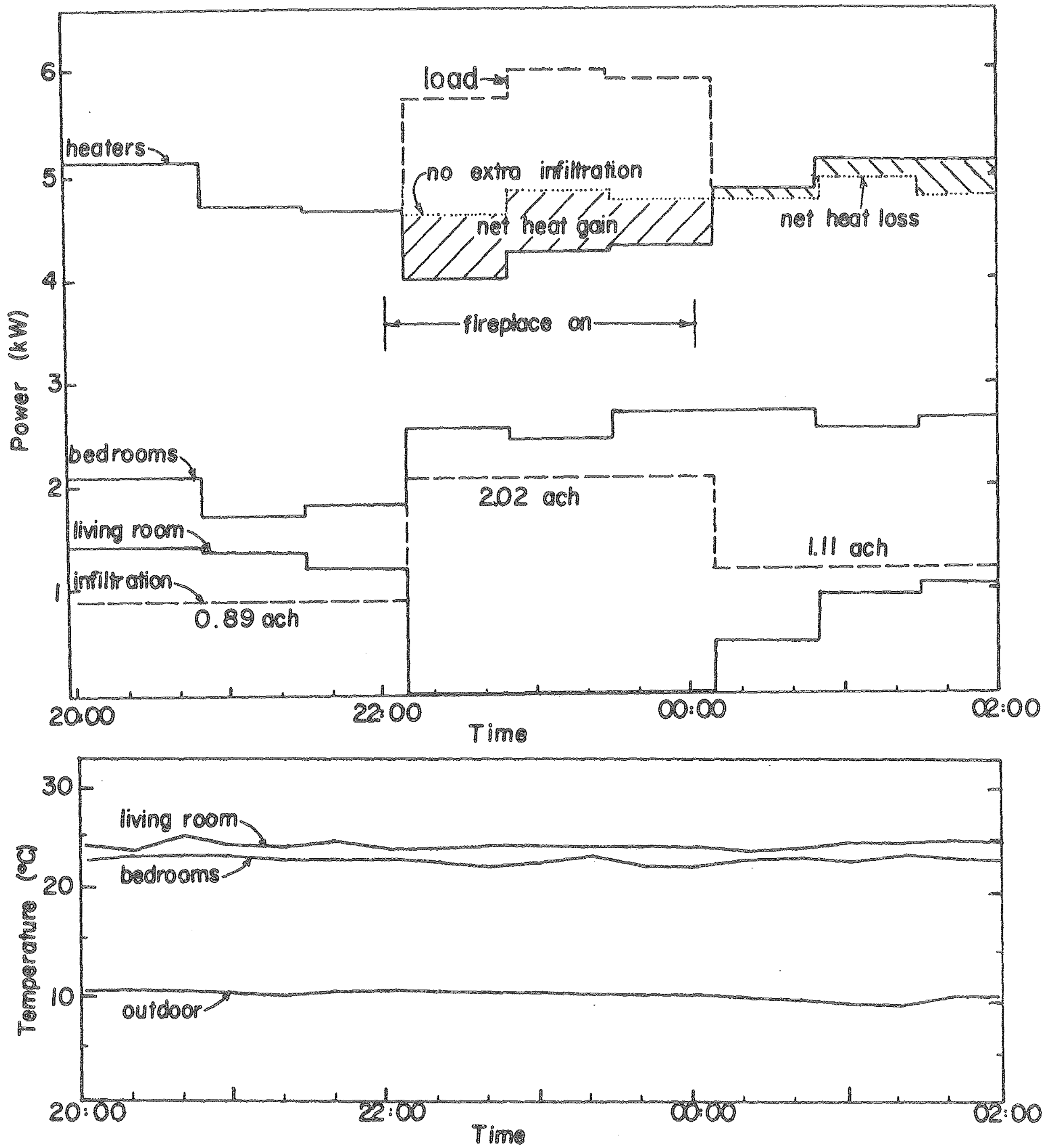


Figure 3. Fireplace efficiency measurements. Top figure, electric heaters consumption in whole house, in bedrooms and living room; calculated heat loads with and without fire-induced air infiltration; infiltration load. Bottom figure, temperatures indoors and outdoors.

from the measured electric consumption and the recorded indoor-outdoor temperature difference for the two periods before and after fireplace operation. The resulting values are 364 W/K and 358 W/K, respectively. By subtracting the contributions of air infiltration we estimate the heat transmission coefficient: 295 W/K and 273 W/K. These estimates for UA are about 20% higher than what we derived in the furnace test discussed before. The discrepancy could be related to ground losses: the crawlspace temperature is affected by outdoor and indoor temperatures, which were measured, and by ground temperature, which was not. Two months separate the two tests; a change in ground temperature may have caused differences in heat load not accounted for by indoor-outdoor temperature difference alone. Varying wind velocity may cause some variation in heat transmission, although this particular house is so well shielded (as evidenced by surface pressure measurements under different wind conditions), that we do not consider this factor very important.

The arithmetic average of the transmission coefficients deduced from periods 1 and 3, 284 W/K, is used in conjunction with the measured values for air infiltration and indoor and outdoor temperatures to estimate the heat load during fireplace operation. Of course, the direct multiplication of temperature difference by heat loss coefficient implicitly neglects all transient effects. The resulting instantaneous heat load is plotted as a dashed line in the top Fig. 3. Its substantial increase during fireplace operation, compared to periods 1 and 3, is due to the contribution of air infiltration, plotted in the same figure in units of kilowatts.

The dotted line in Fig. 3 represents the heat load to which the house would have been subjected without fireplace operation. The net heat gain from the fireplace (shaded area in Fig. 3) is the difference between that heat load (dotted line) and the measured electricity consumption by all heaters. The average net heat gain during the middle period was thus determined as 526 watt. (We shifted the middle period by 10 minutes with respect to actual fireplace operation, partly for the transients involved in fireplace start and stop, partly for data reduction convenience.)

The fireplace was burning natural gas at an average rate of 46,450 watt. Thus the net efficiency in this test was a mere 1.1%! Preliminary tests with wood indicate efficiencies still less than 5%. Note that this test was conducted in mild weather (10 $^{\circ}$C). Colder temperatures would probably yield negative efficiencies.

If we look at period 3, after the gas burners were turned off, we encounter other effects that could change the 1.1% figure slightly. For instance, the net heat gain after fireplace operation (narrow shaded area in top Fig. 3) is negative, if we assume that the air infiltration would have been constant at 0.89 ach in the absence of a fire. But we must also consider the possible gain from delayed thermal radiation from the hearth, after the fire. Closer scrutiny of Fig. 3 reveals several interesting effects: separate plots of the electric consumption in the living room (where the fireplace is located) and in the peripheral rooms display patterns different from that of the overall consumption. In the living room, the electric consumption drops from an average 1,378 watt before, to zero during fireplace operation, reflecting the sizeable local heat gain from the fire. At the same time, the consumption in the peripheral rooms increases by an average 664 watt, counteracting the extra cold air infiltrating through wall cracks.

After the fire has been turned off, both living room and peripheral consumptions do not recover to pre-fire values. The living room consumption appears to creep back to the starting levels, but there is no sign of recovery in the peripheral rooms, although the air infiltration rate drops relatively quickly to a value close to pre-fire conditions. This non-symmetric pattern has been confirmed in several other runs under a variety of conditions. A possible explanation is that of thermal storage: the living room consumption is below pre-fire levels because of delayed heat radiation from the fireplace masonry. The wall surfaces near cracks in the envelope in the outer rooms, in turn, are reheating after being cooled by the extra fire-induced air infiltration. This explanation appears plausible when we observe in Fig. 3 that during the fire the heating consumption in the bedrooms increased less than the concurrent infiltration load. That the bedroom consumption did not drop after the fire was turned off could be the sign of reheating wall surfaces and edges of cracks. Our explanation is consistent with recent evidence that the loads caused by oscillating air flows in and out of cracks may be less than what one would expect on the basis of indoor-outdoor temperature differences. The effect of such mechanisms would likely pass unnoticed by our air temperature sensors, which did not register any change, as shown in the bottom Fig. 3.

Because of the uncertainties related to these effects we cannot justify at this time charging the small net heat loss in period 3 against the fireplace.

## Conclusions

Electric co-heating was presented as a promising method by which one can measure the net efficiency of the system constituted by any heating appliance and a house. This method measures in-situ the net heat gain from the heating system to be tested by the concurrent decrease in electricity consumed by portable heaters distributed throughout the dwelling, and may be used also to determine envelope performance.

While the method seems adequate to measure net efficiencies of a furnace under cycling conditions, it needs refinement with respect to fireplace efficiency measurements. An interesting application of the electric co-heating method, demonstrated in the fireplace test, is the localization of heat loads in individual rooms. A streamlined version of this method could be used in surveys of the existing housing stock, determining separately envelope performance and heating or cooling system efficiency.

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References

[1] J. Chi, G.E. Kelly, "A Method for Estimating the Seasonal Performance of Residential Gas and Oil-Fired Heating Systems." ASHRAE Trans., Vol. 84 (1), 1978.

[2] U. Bonne, J.P. Langmead, "A Short Method to Determine Seasonal Efficiency of Fossil-Fired Heating Systems for Labeling Purposes," ASHRAE Trans., Vol. 84 (1), 1978.

[3] A.L. Berlad, H.C. Lin, J. Batey, F.J. Salzano, W.S. Yu, R.J. Hoppe, T. Allan, "Seasonal Performance and Energy Costs of Oil or Gas-Fired Boilers and Furnaces," Brookhaven National Laboratory Report BNL 50647, March 1977.

[4] E.C. Hise, A.S. Holman, "Heat Balance and Efficiency Measurements of Central, Forced-Air, Residential Gas Furnaces," ASHRAE Trans. Vol 83(1), 1977.

[5] Amer. Soc. of Heat., Refr. and Air-Cond. Eng., "ASHRAE Handbook of Fundamentals," 1977 edition.

[6] A.J. Gadgil, G. Gibson, A.H. Rosenfeld, "TWOZONE Users Manual", LBL Report No. 6840, March 1978.

[7] R.H. Socolow, "The Twin Rivers Program on Energy Conservation in Housing, Highlights and Conclusions." Energy and Building, Vol. 1 (3), April 1978.

[8] C.F. Sepsy, M.F. McBride, R.S. Blancett, "Fuel Utilization in Residences - Apartment Statistical Analysis." ASHRAE Trans., Vol. 85 (1), 1979.

[9] Energy & Environment Division, LBL, "Annual Report 1978." To be published by Lawrence Berkeley Laboratory, Berkeley, CA, 94720, U.S.A.

[10] P.E. Condon, D.T. Grimsrud, M.H. Sherman and R.C. Kammerud, "An Automated Controlled-Flow Air Infiltration Measurement System." To be published in Proc. ASTM Symposium on Air Infiltration and Air Change Rate Measurements, Wash. D.C.,March 1978.

[11] R.C. Sonderegger, "Modeling Residential Heat Load from Experimental Data, The Equivalent Thermal Parameters of a House," Proc. Intl. Conf. on Energy Use Management, Tucson, Arizona, Oct 1977, Pergamon Press.

[12] J. Shelton, and A. Shapiro, "The Woodburner's Encyclopedia," Vermont Crossroads Press, Waitsfield, Vermont, 1976.

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