FORCED VENTILATION FOR COOLING ATTICS IN SUMMER

by

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The potential for air conditioning energy savings using exhaust fans to cool attics was investigated in six occupied townhouses at Twin Rivers, N.J. These houses were compared with similar houses without attic fans. The houses had various levels of instrumentation. Data collected for two summer months in 1977 was the basis for this study. The principal quantities measured were attic and living space temperatures, air conditioner and attic fan usage, together with outside air temperature and solar flux. The attics with fans were substantially cooler. However, the corresponding reduction in heat flux into the living space through the attic insulation is a very small part of the house air conditioning load. Any difference between the air conditioner energy use between houses with and without attic fans is not discernible from other factors which lead to house-to-house variation in air conditioner use.

Key words: Attic fans; air conditioner energy; ventilation.

1. INTRODUCTION

There has been some controversy on how much energy savings, if any, may be realized from the use of fans to ventilate attic spaces [1,2,3]. Both theoretical studies and experimental data have shown that the use of attic fans led to no net energy savings.[4,5] On the other hand, some have claimed large energy savings from fan use [3]. The study reported here was carried out in occupied townhouses at Twin Rivers, New Jersey. Comparisons of air conditioner usage in houses with and without attic fans, made for the same period in summer 77, show no difference which may be ascribed to the use of attic fans. The attic fans were installed late in 1976. No change in the air conditioner energy use pattern between the summers of 1976 and 1977 is discernible either. Simple theoretical calculations indicate that no significant reduction in air conditioner energy use was to be expected from the use of attic fans. The data indicate that the attic fans operated continuously for many hours on hot days and consumed a significant amount of energy. When the energy used by the fan is combined with the air conditioner energy use, it is apparent that the total energy consumption increases when attic fans are used. Moreover, the peak electrical demand also increases. Thus, there is little justification for the use of attic fans at Twin Rivers, either for reducing energy consumption or reducing peak electrical demand.

The method of analysis and the results are presented in Section 2, while a discussion of the results and relevance to other houses is contained in Section 3.

2. THE EXPERIMENTS IN CONTEXT

Since 1972, members of Princeton University's Center for Environmental Studies have been examining residential energy use in a number of townhouses at Twin Rivers [6]. Of these townhouses, twenty six three-bedroom units were instrumented using the 'OMNIBUS' package. In this instrument package, data are collected hourly on 12 channels. Data included living space and attic temperatures, electrical energy use, water heater and air conditioner on-times. In addition, two other houses, instrumented by the National Bureau of Standards,

Reprinted from Summer Attic and Whole House Ventilation, National Bureau of Standards (NBS) Special Publication 548, 1979.

were available for study. In these houses, data from about fifty channels could be recorded as often as every five minutes. This has been named the 'RAPIDSCAN' data acquisition system. One of the Rapidscan houses was also part of the Omnibus set so that this house had two data acquisition systems operating simultaneously. The principal weather variables-- air temperature, wind velocity and direction--and solar flux on a horizontal surface were recorded every twenty minutes at a local weather station.

The study reported here shows data from five townhouses. All five had Omnibus instrumentation and are identified as TR9, TR13, TR16, TR18, and TR27, according to the instrument serial number. Of these, TR9 was also part of the Rapidscan data acquisition system. TR13 did not have an attic fan - the others did. All the houses had received various energy-saving retrofits prior to the start of the attic fan study. The differences between the houses and their instrumentation packages are set out in Table 1. The common data channels

TABLE 1. HOUSE DESCRIPTION AND INSTRUMENTATION

	TR 9	TR 13	TR 16	TR 18	TR 27
Attic insulation	R-30	R-30	R-11	R-11	R-30
Furnace shaft in attic	sealed	sealed	sealed	sealed	sealed
Gaps on attic floor near party walls	sealed	sealed	as built-not sealed	as built-not sealed	sealed
Appliances: water heater, range, clothes dryer	elec.	elec.	elec.	gas	elec.
Attic fan Capacity (cfm) Power (watts)	1000 (2.7A)	No	709 214	713 209	697 214
Air conditioner	All houses had 24000 Btu/hour units which consumed 3.2kW				
Omnibus instrumentation active from:	4/22/75	6/24/75	7/2/75	12/10/75	8/13/76
No. of attic temp. measurements	19	1	5	5	5
Attic fan-on measurement	June, Aug 77	-	Aug 77	Aug 77	Aug 77

for these houses were:

Basement temperature
Downstairs temperature
Upstairs temperature
Air conditioner on-time
Water heater on-time
Thermostat setting.

The standard 'Omnibus' house is equipped with only one attic thermistor, located at mid-height halfway between the trapdoor and the closer party wall. In TR16, TR18, and TR27, there were four additional thermistors, under insulation, on floor (2), and below roof.

The Rapidscan measurement in TR9 included two temperatures on the underside of the roof, one for the East-slanted roof and one for the West-slanted roof. There were also two infrared radiometers (sometimes known as pyrgeometers) installed in the attic - one pointing up and the other down - to measure the infrared radiation emitted by the roof and the floor of the attic. Major appliances were also monitored.

3. DOES THE ATTIC FAN SAVE ANYTHING?

A) One house - one summer

In this section, some of the results of our study and analysis are presented. There are a number of different ways of determining the influence of the attic fans on the heat balance of the house. One way is by comparing days of similar weather and household occupancy with the attic fan on and with the fan off. During the summer of 77, the attic fan switch was turned off for two weeks. (Note that the fan is thermostatically controlled so that the fan does not run continuously even when the switch is turned on.) It was difficult to watch the weather between days with the fan on and fan off even when the outside temperature and solar flux were the only two weather variables considered. The reason, apparently, is that the summer period in New Jersey is short and extremely variable in temperature and cloudiness. This method, which has been used by other researchers [5], could not be used for our data set.

B) Two houses - one summer

The second approach was to examine the changes in a number of variables with the time of day, averaged over long periods, - one month or longer. Twenty four data points are created for each variable, one for each hour of the day. In this data reduction, the day-to-day "random" weather patterns would be eliminated but the aggregated variables would still retain the average variation with time of day. One period considered consists of about four weeks during August 1977. The average outside temperature and horizontal solar flux at Twin Rivers for this period are shown in Fig. 1. The corresponding variation of air conditioner use, attic fan use (where applicable) and attic-upstairs temperature differences were calculated from data for a number of townhouses, six of which had attic fans installed. Two houses were chosen that had attic retrofits A and D*, i.e. they had R-30 ($5.29 m^2$ °C/W) insulation on the floor, and openings around the furnace flue and along the party walls had been sealed. Moreover, both houses were oriented the same way - the windows and doors face roughly east and west. The principal physical difference between the two houses is that one of them (TR27) was equipped with a thermostatically controlled attic fan while the other (TR13) was not.

Fig. 2 shows the average time-of-day variation of $T_A - T_U$ (attic temperature** minus

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*For a description of Twin Rivers retrofits see Ref. 7.

**Unless otherwise stated, attic temperature means the mid-attic air temperature and is denoted by T_A. For consistency all the computations are carried out using this value, which was measured by a thermistor in the same location in all attics. The errors involved with this simplification are discussed in the Appendix.

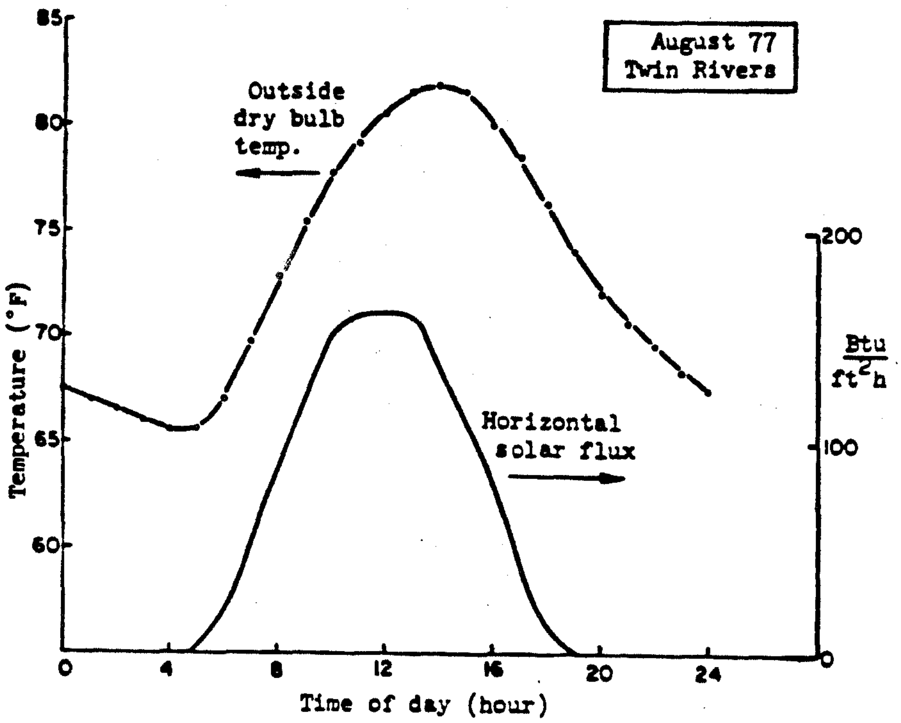
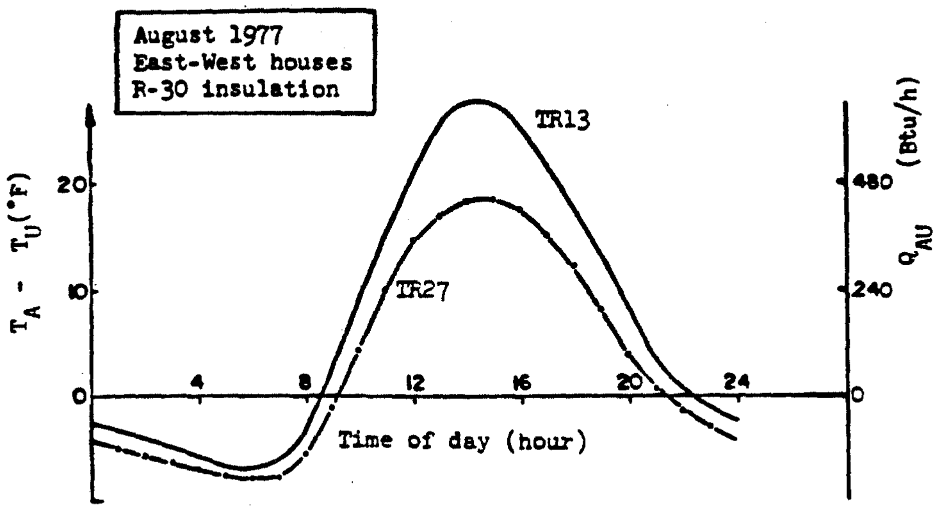


Figure 1. Average hourly variation of solar flux and outside air temperature.

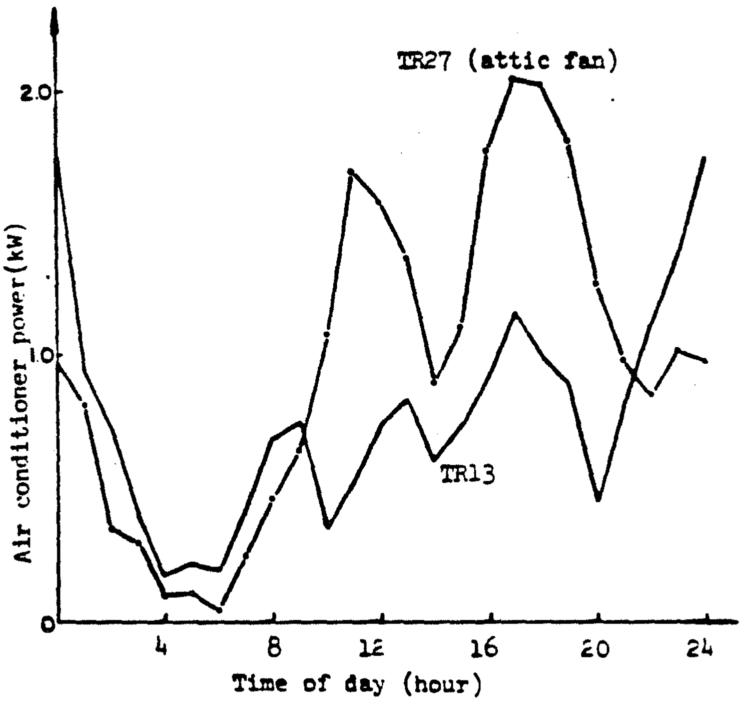
upstairs temperature), air conditioner input power, and attic fan on-time for August 1977. Several features of Fig. 2 stand out. The daytime attic-upstairs temperature differences in the "fan" attic are substantially lower, the maximum reduction in temperature difference being 8.9°F (4.9°C). The graph for T_A - T_U also shows the heat transfer rate from attic to upstairs corresponding to the temperature difference, obtained with an R-value for the attic floor of 26 (4.58 m^2 °C/W).* The reduction in heat flow for an 8.9°F (4.9°C) drop in T_A-T_U amounts to 240 Btu/h (70 watt). Since the 24000 Btu/h (7.0kW) air conditioner requires 3.2kW to operate, the corresponding reduction in air conditioner power is 32 watts, a small part of the total air conditioner power in the middle of the day - typically 1000 to 2000 watts. The average power consumption by the attic fan at this time is 160 watts and far exceeds the reduction in air conditioner power.

At other hours of the day, the reduction in ceiling heat flux and corresponding savings in air conditioner power are smaller, but the attic fan power remains large for most of the day (Fig. 2). The daily averages of ceiling heat flux, air conditioner and attic fan energy use for August 77 may be obtained from the area under the curves in Fig. 2. For instance, the area under the attic fan on-time curve in Fig. 2 (c) indicates that the attic fan is on for 6.82 hours on an average day, thus consuming 1446 watt-hours. The average daily ceiling heat fluxes for the two houses may be obtained from the area enclosed by the T_A - T_U curves in Fig. 2(a) and the horizontal axis. The difference between the two values is the reduction in ceiling heat flux on an average day — 2147 Btu (2264kJ), again assuming that the ceiling is R-26 (4.58 m^2 °C/W). This drop in heat flux will result in a reduction in air conditioner energy use of 286 watt hours on an average day. The average daily air conditioner energy uses, obtained from Fig. 2(b), are 17.6 kWh and 23.4 kWh for TR13 and TR27 respectively. The reduction in daily air conditioner energy use of 286 watt hours

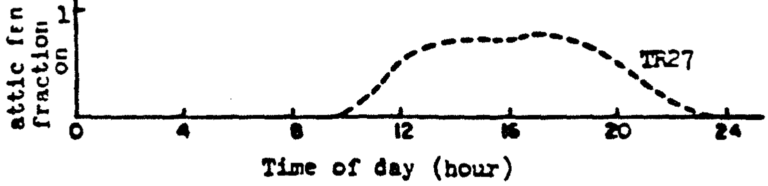
* The insulation effectiveness for two of the six Twin Rivers townhouses had been evaluated by the National Bureau of Standards. One of these houses had R-11 insulation, and the other R-30. The overall R-values of the attic floor were measured to be 10.3 and 26.4, respectively [11]. These values are within 12% of the nominal values of the insulation itself.



a) Attic - upstairs temperature differences



(b) Air conditioner power consumption



(c) Attic fan on-time

Figure 2. Average variation with time of day

brought about by attic fan use is a negligible part of the total air conditioner energy use. The attic fan uses an additional 1446 watt hours of energy per day, so that the total energy consumption for cooling is higher by (1446 -286) watt hours if attic fans are used.

The most striking feature of the data in Fig. 2(b) is that the air conditioner use patterns in the two dwellings are quite different. The house with the attic fan, TR27, uses more energy during the day. Large differences are also seen between the air conditioner power for the other houses in our study. Even though the units are nominally identical in construction, where minor differences might explain some of the variation in air conditioner use, the bulk of the variation is believed to depend on the behavior of the resident. In reference 8, Sonderegger showed statistically that a major part of the variation in heating energy use is ascribable to resident behavior. Air conditioner energy use is even more resident-dependent for the following reasons:

(a) Cooling need is more discretionary.
(b) The inside-outside temperature differences are much smaller in summer so that thermostat readjustment of 1° has a larger percentage effect.
(c) For a significant portion of the summer, the outside temperature is low enough to permit cooling by opening windows. But if windows are not opened then excessive internal heat built up from appliances, people and the sun can only be removed by the air conditioner. The ability or desire to take advantage of cool outside air, therefore, may make a noticeable difference in air conditioner use.

C) One house - two summers

Given these unavoidable house-to-house variations in air conditioner energy use, it is difficult to discern the effect of small energy-saving retrofits unless a very large sample is available for comparison. The alternative, of comparing a house for two intervals in the same summer with and without the attic fan on, was precluded earlier because of the variability of summer weather and the lack of exact comparison situations. A third approach to identify the effect of the attic fan was to look at data from the same house for two different summers where the attic fan was installed in the intervening winter. Instead of attempting to find identical days in the two periods, this method identifies the dependence of air conditioner use on weather by scatter plots and regressions.

The relevant weather variables are outside air temperature, solar flux, wind velocity and direction, and outdoor humidity. The data may be aggregrated into hourly or longer intervals. In order to reduce the effects of thermal storage, longer time intervals are desirable. However, the air conditioner use between midnight and sunrise is low and the attic fan never runs during this period. The daylight period - 8 a.m. to 8 p.m. - was the interval examined in this study.

Woteki has shown that both daily (24-hour) and twelve-hour (8 a.m. to 8 p.m.) air conditioner use may be equally well modeled whether one takes "cooling degree days" or "cooling degree hours" as the independent variable [9]. His analysis also shows that regression fits are not improved by including the solar flux, wind, or humidity. This lack of fit is surprising but is convenient because we may model the air conditioner use by a single weather-dependent variable, the inside-outside temperature difference.

For the present study the average temperature difference between outside and inside ($T_O - T_I$) between 8 a.m. and 8 p.m. was taken to be the independent variable. The inside temperature itself was obtained by averaging the house upstairs and downstairs temperature readings. The dependent variable was the average air conditioner power (A/C) during the interval. Scatterplots of A/C vs $T_O - T_I$ for TR16 and TR18 are presented in Fig. 3 and 4 for both summer 76 and a part of summer 77. The periods covered are from June to mid-September of 1976 and June and August of 1977. Both attics have R-11 insulation (1.94 m^2 °C/W) and fans were installed late in 1976.

The most important observation to be made is that the scatter plots for the two summers in both houses overlay each other. The air conditioner energy use patterns for the summers with and without the attic fan are indistinguishable.

Thus, using three different methods of analysis we were unable to discern any energy savings brought about by the use of attic fans. Data were presented for four houses - two

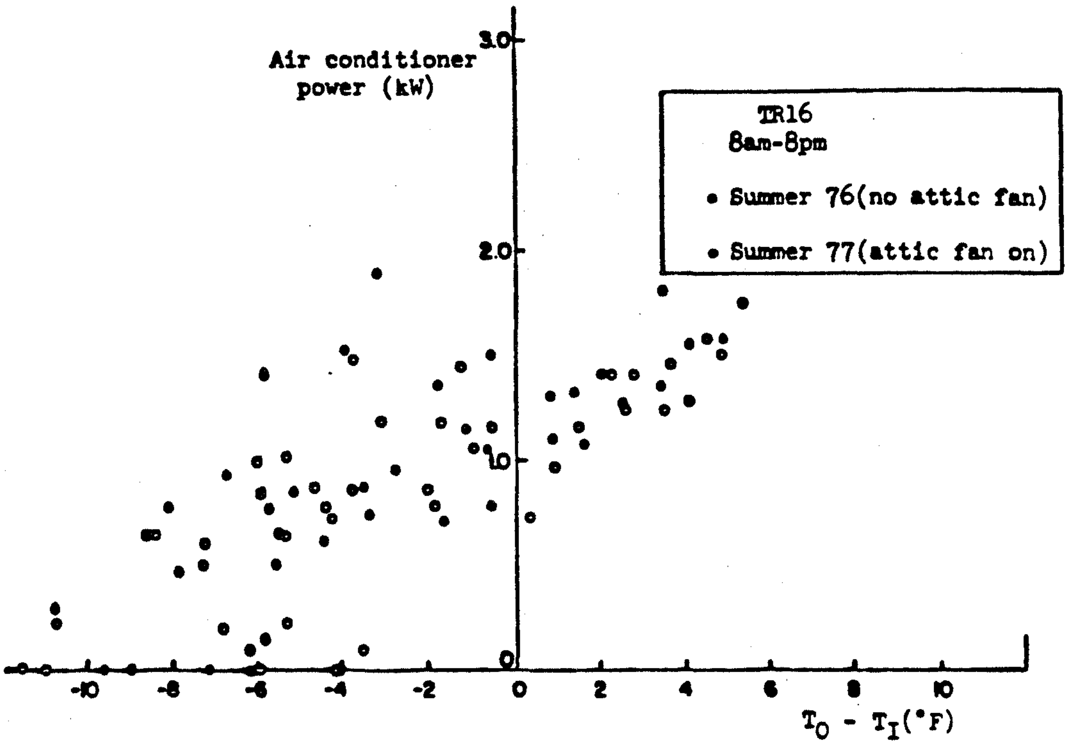


Figure 3. Air conditioner power vs. indoor-outdoor temperature difference

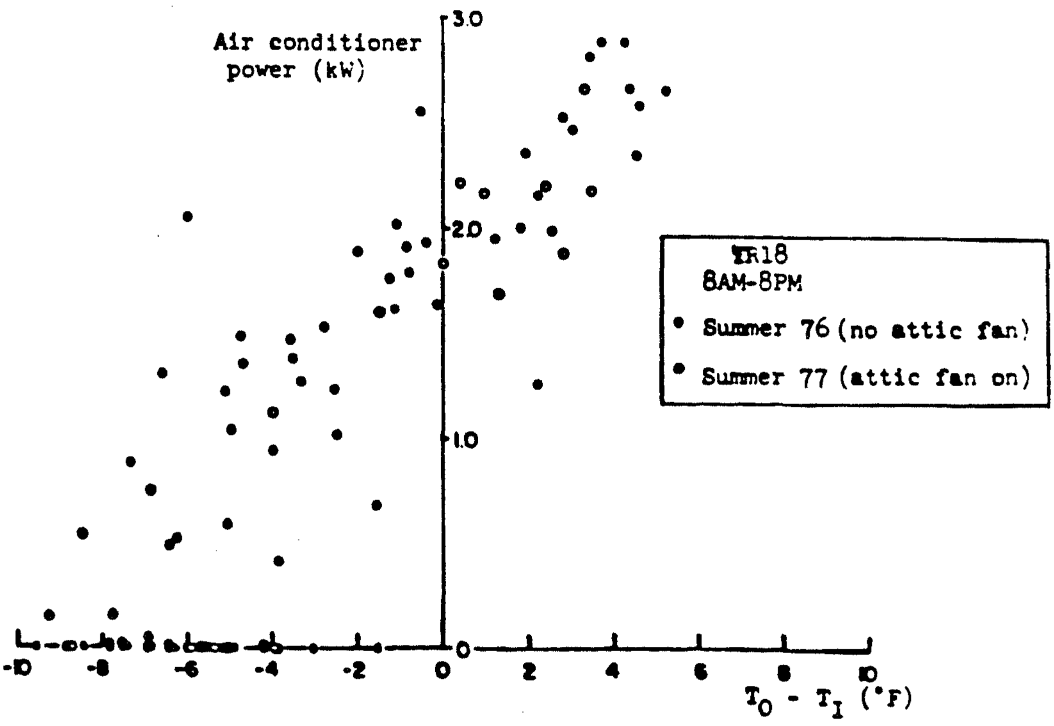


Figure 4. Air conditioner power vs indoor-outdoor temperature difference

ith R-11 (1.94 m^2 °C/W) insulation on the attic floor and the other two with R-30 (5.29 m^2 C/W)

The second approach showed that the maximum attic cooling from the use of attic fans ould result in negligible air conditioner energy savings and would in fact increase both he total energy used (by the air conditioner and attic fan) as well their peak electrical ower requirement.

The summer in Twin Rivers, New Jersey, is relatively mild - at least there are many ays when it is cool outside, i.e. $T_O < T_I$. It has been claimed that on mild days, use of at-ic fans may eliminate the need for air conditioning altogether and result in energy savings. owever, even for mild days, when the hot attic is a larger component of the cooling load, e do not see reduction in air conditioner use when attic fans are operating (Figs. 3 and 4).

DISCUSSION

The attic fans tested in this study showed no savings in net energy used for cooling. hese results match those of other researchers in different climatic regions of the U.S.[1,4,5].

reason that attic fans do not save energy is because the heat gain through R-11 1.94 m^2·°C/W) or R-30 (5.29 m^2·°C/W) insulation is small (even though the attic is quite ot) and the fan requires more energy to operate than the savings from reduced ceiling heat ain. If the insulation level was much less, then attic fans would actually save energy, al-hough even in that case adding insulation would save energy in a more cost-effective way. he optimum level of insulation, determined from winter energy requirements, is quite large - arger than the present standards - and larger than the R-30 (5.29 m^2 °C/W) used here [5]. For uch highly-insulated attics, the ceiling heat gain during summer would be so small that at-ic fans would be even less effective than for present houses.

One way by which forced ventilation may be effective in reducing cooling energy needs s in whole house fans. For instance, a glance at Fig. 3 or 4 reveals that much of the air onditioner use took place when the outside was cooler than the house interior: $T_O - T_I < 0$. n such a case ventilation should replace the air conditioner to save energy. The optimum entilation system to meet this need warrants further study.

We have indicated why expending energy to cool the attic is a losing proposition in eavily-insulated attics. But if increased ventilation could be obtained without power, then t may be cost effective although the percentage savings would be very small. Most natural entilation systems are wind-dependent, and increased ventilation entails increasing the vent pening area. This is beneficial in summer but increases winter heat loss so that it is not n ideal system. One venting arrangement - the ridge vent - takes advantage of the stack ef-ect the attic. The venting rate is much higher in summer than in the winter, which is referable [10]. Other venting arrangements may be devised, using a reflective material be-ow the roof joists to both cool the roof directly by the chimney effect and isolate the at-ic floor from infrared roof radiation. Such a "solar-powered" attic vent would be most ef-ective on sunny hot days, when it is most needed. Other arrangements, including closing and pening vents seasonally, may also be devised for optimal venting. However, it should be orne in mind that the heat gain through an insulated attic is small and only small energy avings may be expected.

Some energy conserving measures, like increased attic or wall insulation, are probably ective both in the summer and winter in making the living space comfortable with reduced ergy use. Other conservation measures have to be selected to optimise the house for both mmer and winter, e.g. location of windows and overhangs to maximize winter solar heat gain nd minimize summer solar heat gain. A third category of conservation measures is based on eparate optima for summer and winter but involving a simple changeover in between. The op-imum strategy for attic ventilation falls in either the second or the third category. Dou-le season optimization is a promising direction for future conservation research.

Appendix

Temperature Distribution in Attics

The sun heats the roof, which conducts heat to the attic air. Also, the hot underside of the roof radiates infrared energy directly to the attic floor. It is the temperature on the attic floor surface that primarily determines the extent of heat transmission to the living space below the attic. Therefore, we need to know the attic floor temperature and how it is altered by the fan. We will show in this appendix that the heat transmitted into the living space, calculated using the mid-attic air temperature, is somewhat larger than that based on the attic floor surface temperature. Furthermore, we will show that this calculation exaggerates the reduction in cooling load brought about by the use of the fan. Thus the energy savings calculated in Section 2 using the data of Fig. 2 are larger than the actual savings, i.e. the attic fan reduces cooling load even less.

Let T_A, T_{AF}, T_U be the average temperature of the mid-attic air, the attic floor surface and the upper floor air respectively. The heat conduction through the attic insulation is

$$Q = U_F A_F (T_{AF} - T_U)$$

where U_F is the thermal conductance of the attic floor and A_F is its area. If the mid-attic temperature is used to estimate Q, then this estimate is

$$\bar{Q} = U_F A_F (T_A - T_U)$$

The question is how does $\bar{Q}$ compare with Q. Six of the houses had thermistors both in mid-attic and on the floor surface. During the day the mid-attic air was always warmer than the attic floor, so that $\bar{Q} > Q$. A typical day with no attic fan operating in TR 9 is depicted in Fig. 5. Denoting conditions with the fan on by primed quantities, we have

$$Q' = U_F A_F (T'_{AF} - T_U)$$

and

$$\bar{Q}' = U_F A_F (T'_A - T_U)$$

The reduction of $\bar{Q}$ by the attic fan is:

$$\Delta\bar{Q} = \bar{Q} - \bar{Q}' = U_F A_F (T_A - T'_A)$$

while the true heat flux reduction is:

$$\Delta Q = U_F A_F (T_{AF} - T'_{AF})$$

The data show that with the attic fan operating, the temperature difference between the mid-attic and the attic floor is reduced, i.e:

$$T_A - T_{AF} > T'_A - T'_{AF}.$$

so that:

$$\Delta\bar{Q} - \Delta Q = U_F A_F (T_A - T_A' - T_{AF} + T'_{AF}) > 0$$

In other words, the actual reduction in heat flux is less than that calculated using the mid-attic air temperatures.

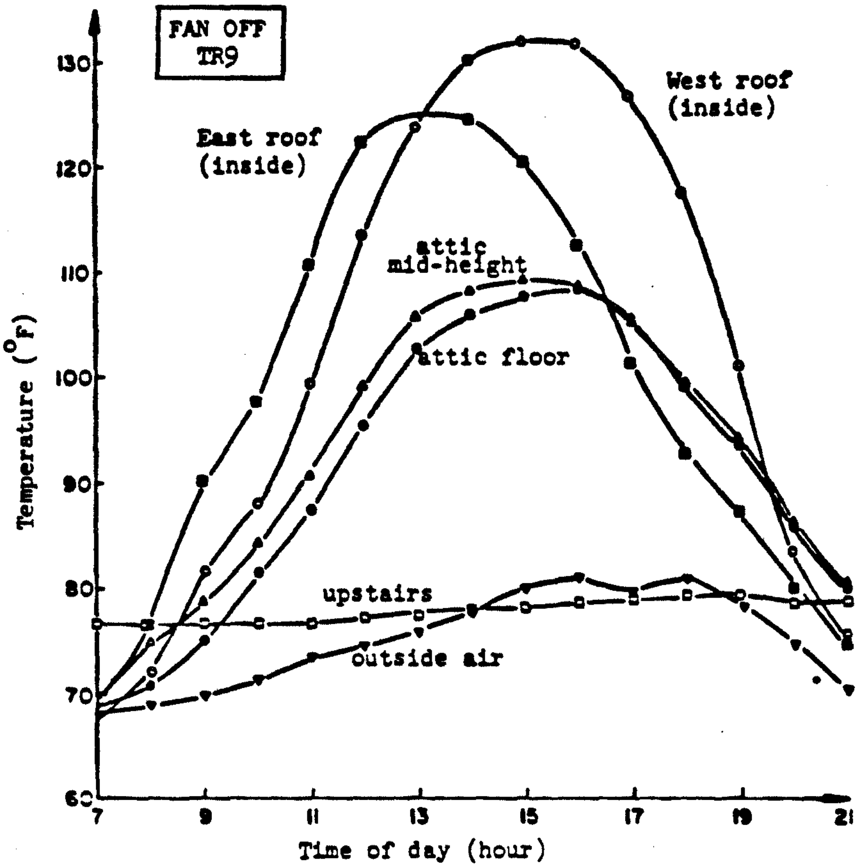


Figure 5. Distribution of temperature in the attic

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Acknowledgements

This work was supported by the U.S. Department of Energy under contract. We wish to acknowledge helpful discussions with and support from the Home Ventilating Institute, who supplied the calibrated attic fans for TR10, TR16, TR18, and TR27. The National Bureau of Standards permitted us to use their instrumented houses for our experiments and even provided us with their computer programs. We wish to thank Mr. Kenneth Gadsby and Mr. Roy Crosby for help with the experiments.

Questions and Answers

John A. Reagan, NASA Langley Research Center, Hampton, Va.:

How do your measurements and calculations of reduction in roof heat gain compare with ASHRAE Method predictions which ascribe an additional R-value to the attic air space based on the added cfm/ft^2 ventilation produced by the addition of attic ventilators?

Dutt and Harrje: The ASHRAE method for calculating the heat gain through attics is based on experiments conducted by Professor Joy.* The experiments were conducted under steady-state conditions and the air flow was across the roof and ceiling joists through gable vents. The Twin Rivers houses with soffit vents and a roof-mounted attic fan subject to actual weather conditions represent a different case. Nevertheless, if Professor Joy's data (Fig. 8 in his paper) are used, the following results are obtained (approximate).

R-values

	Ceiling	Roof	Attic Space	
			with fan	w/o fan
R-11 insulation	10	1	9	3
R-30 insulation	26	1	9	3

Notes: The flow rate with the fan on is 1.0 cfm/ft^2 of floor area, while with the fan off it is around 0.2 cfm/ft^2. The effective resistance of the attic air space can then be obtained from Fig. 8 (Professor Joy) for kraft-breather insulation and a ventilation air temperature of 85°F. These conditions are closest to our experimental case at max. $T_A - T_U$ (see Fig. 1 and 2 of our paper). The R-values of the ceiling are based on measurements.

The total R-value of the attic from living-space ceiling to the roof exterior surface (R total) increases from 14 to 20 for R-11 attics and from 30 to 36 for R-30 attics. The corresponding reductions in attic heat flux for any given sol-air temperature and room temperature are 6/14 (or 43%) and 6/30 (or 20%) for R-11 and R-30 attics. For the data shown in our Fig. 2(a) the peak heat flux reduction is about 30% with R-30 insulation, which is higher than Professor Joy's steady-state value of 20%. Despite this reduction in heat flux, no measurable A/C savings are observed, as might be expected since heat gain through an R-30 attic represents only 5% of the A/C energy use (see Fig. 2 and discussion in our paper.)

Home Ventilating Institute (HVI): 5 questions with authors' responses.

1. The paper states that "corresponding variation of air conditioner use, attic fan use (where applicable) and attic-upstairs temperature differences were calculated from a number of townhouses, six of which had attic fans installed." Does Fig. 2 represent such calculations or actual measurements at the two specific houses?

Response: Fig. 2 (a, b, and c) represents data from actual measurements in the two houses. The top figure (a) carries two labels for the ordinate: T_A-T_U (°F) and Q_{AU}. The data shown are the temperature differences T_A-T_U. These temperature differences may be used to calculate the heat transfer through the attic floor, Q_{AU}, by multiplying by the "UA" value of the floor.

* F. A. Joy, "Improving Attic Space Insulating Values," ASHRAE Transactions, 64, 251 (1958).

2. Were comparisons made betwen Houses TR 16 and TR 18 with R-11 ceiling insulation as for the two R-30 houses in Fig. 2? If so, were there different patterns of temperatures, air conditioner use and attic fan on-time? Were differences in the two houses' thermostat settings, air conditioner efficiency and load factors considered?

Response: TR 16 and TR 18 with R-11 insulation both had attic fans installed and exhibit almost the same (T_A-T_U) pattern as shown in Fig. 2(a) for TR 27, which has R-30 insulation.

We measured but did not include the thermostat settings data in the paper. Since the air conditioner is somewhat undersized, the interior temperature often exceeds the thermostat setting. The interior temperature is therefore a more meaningful variable. Consequently, the analysis was based on measured temperatures only. The air conditioners were of the same make and rating. Sizing of the units was such that operation was continuous for a number of hours on the hottest days.

3. Were respective thermostat settings, air conditioner efficiency and load factors considered in the comparisons of the two R-30 houses in Fig. 2?

Response: The data in Fig. 2 are based on a comparison of two identical houses - one with fan on, the other with fan off, for one month's identical weather. The temperature difference is the important parameter.

4. Is the statement that no energy savings resulted from power attic venting in R-11 houses based on calculations or measurements?

Response: Experimental data were used to determine that no energy savings resulted from using attic fans.

5. Inasmuch as the paper's conclusions are based on R-30 and higher optimums of ceiling insulation for northern heating requirements, perhaps it would be appropriate to note that many authorities consider the economics of insulation quite distinct for heating and cooling. The trade-offs between insulation and ventilation can prove quite different where cooling rather than heating is the main energy user.

Response: Our study was conducted at Twin Rivers, where cooling is a significant energy user, though certainly less than heating energy, and is typical of the Northeast. Savings in the form of reduced energy entering from the attic using R-30 insulation during the summer cooling season are shown in heat flux versus time plots in the paper by Dr. Richard Grot in this workshop.

Arnold M. Kronstadt, P.E., Collins & Kronstadt, et al, Silver Spring, Md. 5 questions with authors' responses.

1. In view of the "large differences in air conditioner use" among houses in the study, with the bulk of variation ascribed to resident behavior, what measured data support a conclusion that powered attic fans saved no cooling energy? Can any valid conclusion be reached about the effect of any other factor on air conditioning when behavioral variations are not identified and quantified?

Response: The data were taken in real houses under conditions of actual use. The effect of the attic fan was, as predicted, so small that it was undetectable compared to heat transmission factors due to the other causes. The conclusion that can be supported is that measurable savings were not present using attic fans. Behavorial variations do not appear to be quantifiable to the degree that they may be factored out so that any other effect must be studied superimposed on the noise of behavioral variation of A/C use.

2. Were causes determined for the much higher air conditioner use in House TR 27 with power ventilated attic as compared with House TR 13 (Fig. 2) without such ventilation? Might it have been impossible for any attic fan to have had energy impact in this house but possible in another house?

Response: The difference in the patterns of consumption for Houses 27 and 13 shown in Fig. 2 is clearly a behavioral factor. This is why it is vital to make comparisons based on temperature differences between indoor, outdoor, and attic, and to do so over time spaces sufficiently long to cancel out any heat storage effects. Comparison using individual points from data such as shown in Figs. 3 and 4 would result in erroneous conclusions because of large variation caused by behavioral and other non-quantifiable factors in individual houses.

3. The attic fan on-time curve and hours of fan running time related to House TR 27, which had high air conditioner demand, and covered only August. Are data on this house the basis for conclusions that total energy consumption increases and peak electrical demand increases when attic fans are used? If so, would not data for more houses and a longer period be more applicable? Are data available on total attic fan running time related to air conditioner running time, covering other houses and the whole summer?

Response: The conclusion that peak electrical demand increases when an attic fan is used is based on measured attic fan usage rate, and integrated differential temperature from attic to upstairs. This differential temperature is used to calculate the heat load through the attic insulation. We do not rely on actual air conditioner use data, whose variations are determined by many other factors as well.

The late afternoon period on even a warm sunny day activates the attic fan. This is the same period for high A/C usage. Combined, this can only result in higher peak loading on the electric utility.

4. Was radiant heat from the ceiling as affecting comfort measured and evaluated, especially on days when outdoor maximum temperatures were appreciably higher than the low 80s reported in this study?

Response: Ceiling temperatures were measured and found to be reduced by about a degree with attic fan operation. The impact of change of ceiling radiation was not measured by instruments but was rather left to the discretion of the resident. The ultimate judge of comfort is the resident, who adjusts the thermostat till he/she is comfortable. If the resident raised the thermostat when the attic fan was cooling the ceiling, its effect on A/C use was not detectable. Since the A/C usage is fairly sensitive to thermostat manipulation, it is reasonable to conclude that the thermostat adjustment did not accompany attic fan operation. This fits in with our finding of very slight reduction in ceiling temperature and the fact that the affected ceiling is on the second floor while the thermostat is on the first. The temperature reported in the study is that of an average day in August, obtained from averaging a month of data. The occasional very hot day does not contribute significantly to the cooling requirement of the entire season.

5. Can the conclusions about Twin Rivers, which are based on a few two-story townhouses for a short time in cool weather, be applied without qualification to one-story or two-story detached houses in the same community in hotter seasons, or to houses elsewhere with differing roofs, orientation, and heat-humidity-wind conditions?

Response: The relative influence of attic heat load is typical of a wide variety of housing and geographical areas and we would expect these conclusions to hold. However, for single-story construction, one expects the attic to have a greater influence on summer heat loads. In such cases, larger A/C savings from attic retrofits are possible.