#7424

Affordable Cooling with Window Air Conditioners

by Mark P. Ternes

New research shows that replacing low-efficiency window air conditioners with high-efficiency units can produce measurable savings and can be cost-effective in homes with high air conditioning electricity consumption.

While families in southern climates use a considerable amount of energy during the cooling season, conservation programs aimed at reducing air conditioning electricity consumption usually only target homes with central air conditioning, reflecting a general belief that homes with window units can't produce significant savings. Weatherization programs in the South usually involve installation of conservation measures similar to those installed in the North. The measures may reduce air conditioning costs but are usually justified by their ability to reduce space-heating costs. This is because we know more about how weatherization measures affect space-heating consumption than about how they affect air conditioning electricity consumption. Consequently, our knowledge of measures specifically designed to reduce space-cooling costs is limited.

To learn more about how weatherization measures specifically affect air conditioning electricity use in low income households, Oak Ridge National Laboratory conducted a field test with help from The Alliance to Save Energy, Oklahoma's Department of Commerce, Wa-Ro-Ma Tri-County Community Action Foundation, and Public Service Company of Oklahoma. Our goals were to:

- Determine air conditioning electricity consumption in low income houses equipped with window air conditioners.

Mark P. Ternes is a research engineer with Oak Ridge National Laboratory in Tennessee.

M. P. Ternes

Owner-occupied, single-family detached houses were chosen for the Tulsa air conditioner replacement project. Field test results from the project indicate that replacing low-efficiency window air conditioners with high-efficiency units can be cost-effective.

- Quantify the reduction in consumption due to conservation measures installed under the Oklahoma Weatherization Assistance Program (WAP).
- Determine the additional reduction from two measures designed specifically to reduce cooling energy consumption—attic radiant barriers and the replacement of low-efficiency window air conditioners with high efficiency units.

We analyzed the effects of three weatherization approaches, comparing them to a control group of 19 houses that received no weatherization measures. The three approaches were:

- **Weatherization only.** Twenty-two houses were weatherized according to Oklahoma WAP procedures.
- **Radiant barrier installation.** Nineteen houses received the same weatherization measures performed under the Oklahoma WAP plus truss-mounted attic radiant barriers installed by a specially trained crew.[1]
- **Air conditioner replacement.** Eighteen houses received the same weatherization measures plus replacement of

Oklahoma Weatherization Measures

Local weatherization crews installed a standard set of measures, selected specifically to reduce space heating energy consumption, in all field test houses except the control group. They performed airtightening in the houses, which included caulking and weatherstripping and, for the field test, sealing leakage areas using a blower door. Crews increased attic insulation levels to R-19 in 84% of the houses, adding attic vents when necessary. They installed storm windows with insect screens in 90% of the houses where no storm windows existed or where existing ones were beyond repair. Crews also performed minor house repairs in 58% of the houses.

Attic radiant barriers reduce residential cooling costs by decreasing radiation heat transfer across the attic space. A specially trained crew installed radiant barrier material with a kraft paper center and a thin aluminum coating on each side in the radiant barrier houses. They attached the barrier to the underside (faces) of the roof rafters and on the gabled ends of the attic. (See "Radiant Barrier Update," *HE* July/Aug '92, p.7.)

Replacing a low-efficiency air conditioner with a more efficient unit reduces cooling costs for the same amount of cooling. In the air conditioner replacement houses, we replaced one window air conditioner per house having an energy efficiency ratio (EER) up to 7 with a high-efficiency unit of EER greater than or equal to 9 and having about the same capacity as the original unit.[1] In houses with two existing units, we replaced the unit with the greater pre-weatherization electricity consumption.

1. Energy efficiency ratio (EER)—a measure of cooling efficiency—is defined as the capacity in Btu per hour divided by the electrical power input in watts. The higher the EER, the more efficient the air conditioner. EER differs from seasonal energy efficiency ratio (SEER) in that laboratory measurements are made at only one indoor and outdoor test condition and cyclic operation is not considered.

one existing inefficient window air conditioner with an air conditioner of identical capacity and an energy efficiency ratio (EER) of at least 9.0 (see endnote 1 of "Oklahoma Weatherization Measures").[2]

The measures were installed between summers, allowing us to collect a full summer of pre- and post-weatherization data. Public Service Company of Oklahoma metered the consumption of the old and new air conditioners in the 78 houses. We also measured hourly indoor temperatures in rooms with window air conditioners and collected hourly outdoor weather data.

The Test Houses

Our sample of owner-occupied single-family detached houses (which didn't include any mobile homes) were 4–75 years old, averaging 41 years old. Most were single-story, on a crawlspace foundation with no floor insulation. Ninety-one percent had attic insulation, but usually only 1–3 in. thick (less than R-11). Roughly half had no wall insulation. The average floor area was 1,244 ft², most houses had 900–1,500 ft², but the sample range was 594–2,538 ft². Window areas averaged 145 ft², mostly single pane without storm windows. Twenty-seven percent had two window air conditioners. The average age was 8. Most were 4–12 years old. Nameplate cooling capacities were 5,000–28,000 Btu per hour, with about half being 18,000 Btu per hour.

Weatherization Costs

Weatherization costs were nearly the same for each group, averaging $836–$885 per house (see Table 1). Radiant barrier installations averaged $394 per house, including an estimated $250 for material donated by the Reflective Insulation Manufacturers Association. Air conditioner installation (materials and labor) was $811–$1,487, averaging $947.[3]

Crunching the Numbers

We normalized the pre- and post-weatherization air conditioning electricity consumptions to an annual basis using standardized outdoor temperature data and pre-weatherization indoor temperatures for each house. This allowed us to compare the pre- and post-weatherization consumptions on the same basis. We estimated normalized annual air conditioning consumption from the pre- and post-weatherization data using regression models and obtained normalized savings by subtraction.

Test houses used an average of 1,664 kWh per year for air conditioning prior to weatherization, with a range of 8–5,708 kWh per year. One-third of them used less than 1,000 kWh per year (about 10% used less than 250 kWh per year), and 10% used 3,000 kWh per year or more.[4] Average consumption levels among the four groups were quite similar. They were not different at confidence levels down to 75% (see Figure 1).

The low consumption compared to levels typical in central air conditioned houses does not imply a lack of need for air conditioning in the field test homes (see "Indoor Temperature Measurements"). Rather, it probably reflects tight financial situations and use of air conditioning to cool only a portion of each home. Occupants in many houses

Table 1. Average Energy Conservation Measure Costs Per House

Energy conservation measure	Average cost ($) per house		
	Weatherization only	Radiant barrier	Air conditioner replacement
Weatherization			
caulking and weatherstipping	325	367	316
storm windows	351	350	421
attic insulation	109	120	124
repair	52	39	23
total	836	876	884
Radiant barrier	–	394*	–
Air conditioner	–	–	947
Total	836	1,270	1,831

* Assumes $250 per house for material. Cost is estimated because the radiant barrier material was donated.

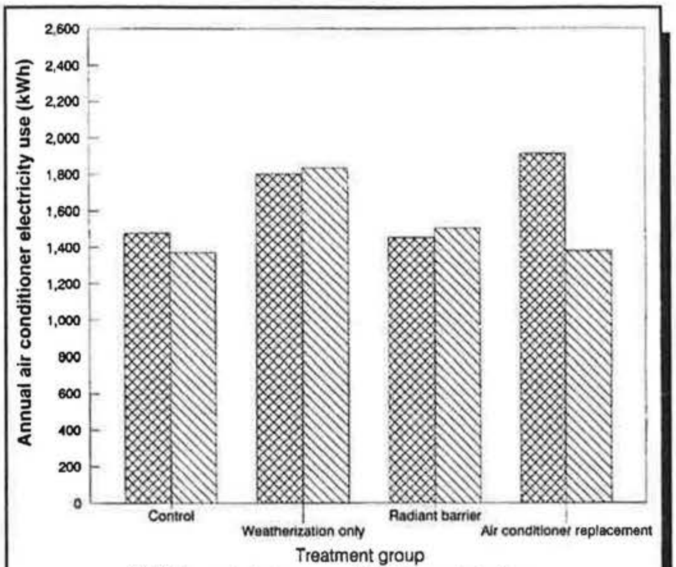


Figure 1. Average normalized pre- and post-weatherization air conditioning electricity consumptions for the four groups of field test houses.

may have accepted discomfort knowing that operating the units would be costly. In some parts of the houses and especially the kitchen, elevated indoor temperatures may have been even more severe than those measured; window units by design only cool limited areas.

Existing low air conditioning electricity consumption poses a dilemma for mangers of low-income weatherization programs in the South, namely how to reduce consumption or keep consumption at already low levels while improving occupant comfort. In our study, the average air conditioning cost was \$119 per year (assuming \$0.07 per kWh), and \$213 for a house using 3,000 kWh per year. Such costs limit the savings one can reasonably expect from weatherization measures directed at reducing air-conditioning use. Even with 50% energy savings, the average annual savings of only \$60–\$100 portends lengthy paybacks for new window air conditioners.

Unexpected Results

Air conditioner electricity consumption actually increased by 31 kWh per year (2%) in the weatherization-only group, and 52 kWh per year (4%) in the radiant barrier group. By comparison the control houses experienced a 7% decrease in consumption, or 107 kWh. (Statistically though, these numbers were not different at a 95% confidence level.) Thus, measures installed under the Oklahoma WAP and adding a truss-mounted attic radiant barrier to a weatherized house with at least R-19 attic insulation did not produce measurable air conditioning electricity savings.

We had expected some cooling savings from the weatherization measures. A comment received from one of the occupants may explain the lack of savings: "I really like the weatherization work my house received, but now I have to sit outside on the front porch later into the summer evening waiting for the house to cool down." Weatherization may have hindered natural air and moisture ventilation during the summer. We suspect that storm windows decreased available window ventilation, that air sealing lowered the natural ventilation rate of the houses, and that attic insulation reduced heat flow from inside the house to attics (which can be below ambient temperatures relatively soon after sunset). This may be especially true in houses cooled by window units that are controlled manually instead of thermostatically. Window air conditioners can be turned off for large portions of the day when a house is unoccupied.

In fact, low measured air conditioning electricity consumptions and high indoor temperatures suggest occupants often ventilated their houses as much as possible and/or turned units off during unoccupied periods. On the other hand, if installed measures prevented heat trapped in the house during unoccupied periods from being dissipated through natural means, greater use of the air conditioners may have negated any potential savings. Air conditioners may have been used at night (or run longer) to achieve reasonably comfortable sleeping temperatures.

As for the radiant barriers, beefed up attic insulation lowered their potential impact, which might have been greater when the attic was less insulated. Post-installation inspections showed that radiant barrier installations were high quality and the reflective surfaces had not degraded due to dust accumulation or other reasons.

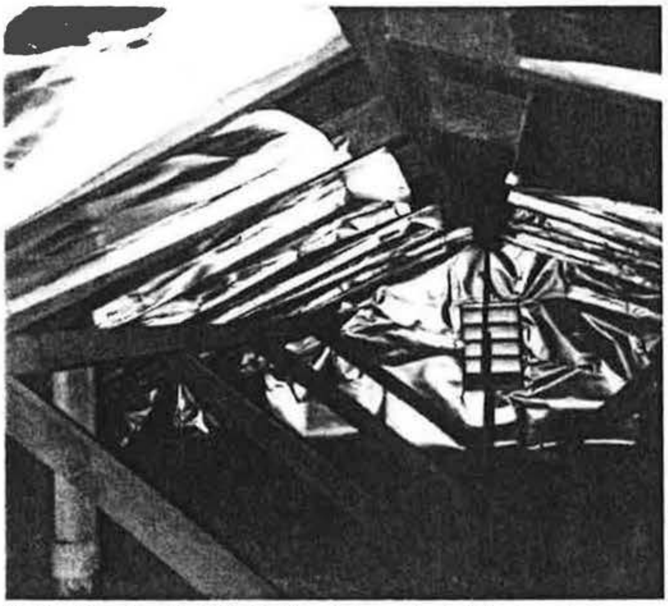
The "take-back effect" (in this case lowering the thermostat to maintain a cooler, more comfortable indoor environment following retrofit) probably doesn't explain the lack of savings we measured for weatherization measures and radiant barriers. Indoor temperatures were used in regression models and indoor temperature changes were accounted for in the normalization.[5]

M. P. Ternes

Mark Hopkins of the Alliance to Save Energy and Larry Wisdom, formerly with the Wa-Ro-Ma Tri-County Community Action Agency, discuss a newly installed air conditioner in one of the Tulsa test homes.

Cool Savings From Replacing Air Conditioners

In contrast to weatherization and radiant barriers, installing energy-efficient replacement window air conditioners saved an average of 535 kWh per year (\$38 per year), or 28% of the group's pre-weatherization cooling



M. P. Ternes

Radiant barriers installed in the Tulsa project did not produce measurable air conditioning electricity savings in houses that already had improved levels of attic insulation.

energy consumption. We attribute the savings to just the installation of high-efficiency air conditioners because no average savings occurred in the weatherized only group. The savings were close to our expectations of about 33%, assuming the new air conditioners (all with an EER of 9) replaced units with EERs of about 6.

While there were houses with both positive and negative savings in each test group, the air conditioner replacement group had the most homes with significant energy savings: eight houses had savings greater than 500 kWh per year, whereas only two or three such "high-savings" houses were in each of the other three groups (see Figure 2). The only two houses with savings greater than 1,500 kWh per year were both in the air conditioner replacement group which also had the fewest houses with negative savings and only one with large negative savings (consumption increases greater than 500 kWh per year).

Although about 75% of the houses in the weatherization-only group experienced positive savings (about the same as in the air conditioner replacement group), the magnitude of the negative savings in the remaining weatherization-only houses was quite large.

Knowing pre-weatherization consumption, one can generally predict what the electricity savings will be. And in fact, savings in the air conditioner replacement group were generally linearly dependent on the pre-weatherization air conditioning electricity consumption (see Figure 3). For example, houses with high consumption had higher savings while houses with low consumption had lower savings. The average savings for four houses with pre-weatherization consumptions greater than 2,750 kWh per year was 1,503 kWh per year (41% of their average pre-weatherization consumption), nearly three times that observed for the group as a whole.

Using a total resource test, we confirmed that upgrading to high-efficiency units without considering pre-weatherization consumption may not be cost-effective. (A total resource test generally includes all costs associated with the measure, regardless of who pays for them, and all benefits from the measure, regardless of who receives them. In this analysis, we conservatively limited benefits to electricity savings.) For houses with pre-weatherization air conditioning electricity consumption greater than 2,750 kWh per year, the replacements were cost-effective assuming an installation cost of $739 (see Table 2).

Recommendations

Replacing low-efficiency window air conditioners with high-efficiency units is cost-effective in houses with high pre-weatherization air conditioning electricity consumption and should be considered an option in programs directed at reducing air conditioning electricity consumption. However, the cost-effectiveness of this measure *must* be verified in each house before installation. Initial air conditioning electricity consumption can be low in many low-income households which provides a ceiling for attainable savings. Options that improve cost-effectiveness may make air conditioner replacements attractive in a

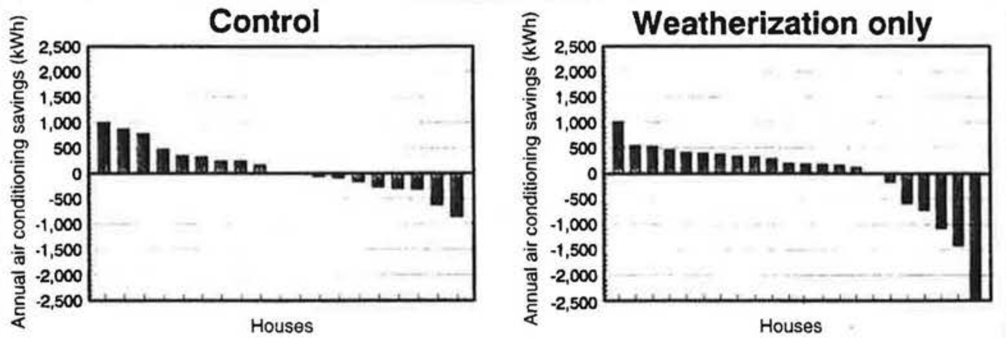


Figure 2. Distribution of individual normalized house air conditioning electricity savings for the four groups of field test houses.

broader range of houses. Measures chosen based on effectiveness at reducing space-heating consumption, continue to be justified on that basis only.

Truss-mounted attic radiant barriers did not produce measurable air conditioning electricity savings in houses that already had improved levels of attic insulation and were cooled by one or two window air conditioners. They should not be included in programs if better alternatives are available or until further testing demonstrates energy savings or other benefits in this type of housing. (Comfort improvements, especially in the portions of the houses that were not air conditioned, were not addressed in this study, but should be researched further.)

Unlike space heating systems, the need for space-cooling systems to increase personal safety and reduce suffering is not generally accepted. Yet this study indicates occupants of houses in the South that use little or no space cooling are uncomfortable and may even face health risks

Table 2. Economics of air conditioner replacements

	Installing replacement air conditioners in all houses	Installing replacement air conditioners in house with pre-weatherization air conditioning consumption greater than 2,750 kWh per year
Average annual savings[1]	535 kWh $38	1,503 kWh $107
Average estimated installation cost[2]	$739	$786
Benefit-to-cost ratio[3]		
10-year service lifetime	0.41	1.08
15-year service lifetime	0.55	1.47
Simple payback period	19.3 years	7.3 years

1. Dollar savings were based on an electricity cost of $0.07 per kWh, the 1990 cost for electricity in the Tulsa area during the summer months for any monthly consumption above 1,000 kWh.
2. Installation costs were estimated for a weatherization program. Costs actually incurred under the field test were high because of the experimental nature of the study.
3. Discount factors for average fuel price escalation and based on a 4.6% discount rate were used in the calculations. Ten years is the median lifetime reported by ASHRAE for window air conditioners, while lifetimes of 15 years are reported for other air conditioning equipment.

Indoor Temperature Measurements

We monitored indoor temperatures in each of the houses in the rooms with the window air conditioners. If two air conditioners were in a house, we monitored the indoor temperature in the room with the air conditioner operated most (as reported by the occupants). Summer indoor temperatures often were far above the 72–81°F comfort zone (at 50% relative humidity) prescribed by ASHRAE. It's likely that some indoor temperatures approached heat stroke thresholds (95°F at 50% relative humidity) as identified by ASHRAE's *Handbook of Fundamentals.*

Average indoor temperatures in 19 of 78 houses with annual pre-weatherization air conditioning electricity consumption *less than 750 kWh* remained above 83°F and were as high as 89°F during 41 summer days when the average outdoor temperature was greater than or equal to 86°F (see Figure 4). Outdoor temperatures rarely dropped below 80°F on these 41 days. In contrast, indoor temperatures fluctuated between 77°F and 82°F in 19 houses that consistently used their air conditioners (with pre-weatherization consumption *greater than 2,500 kWh* per year).

Daily temperature profiles for the houses with pre-weatherization air conditioning electricity consumption less than 750 kWh clearly demonstrate the inability of limited air conditioner use combined with natural ventilation to produce comfortable indoor temperatures throughout the summer (see Figure 5). Comfort zone temperatures inside the house were achieved from this approach only for summer days when the average outdoor temperature was less than 78°F. For hotter days (82 such days occurred during the pre-weatherization summer), average indoor temperatures remained above 85°F at midnight.

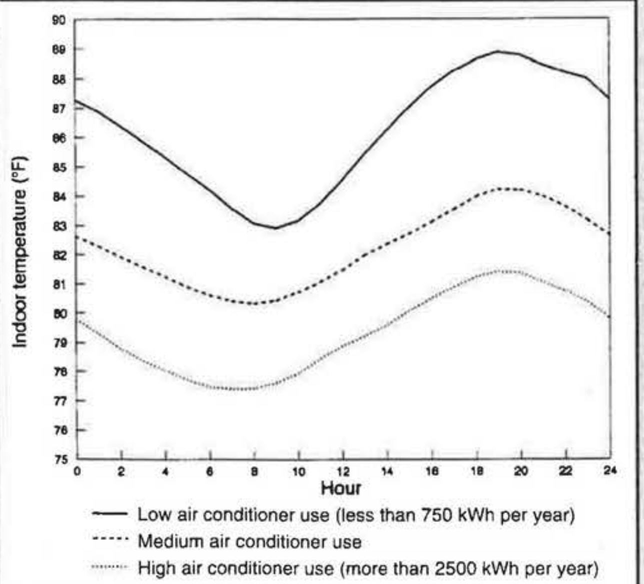


Figure 4. Daily temperature profiles—41 hot summer days

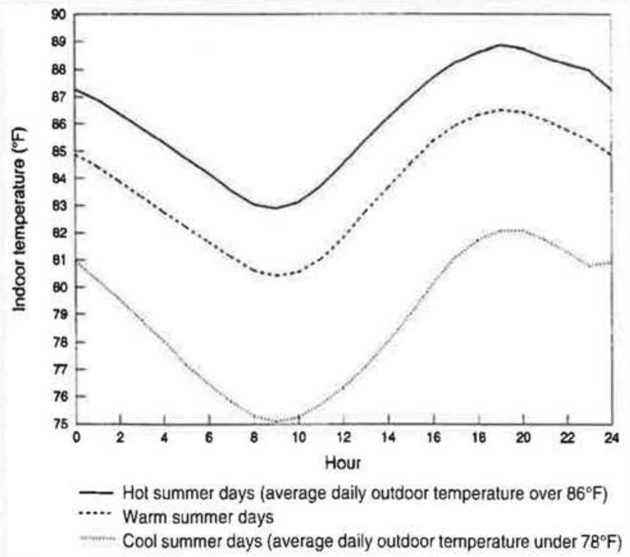


Figure 5. Daily temperature profiles—houses with low air conditioner use

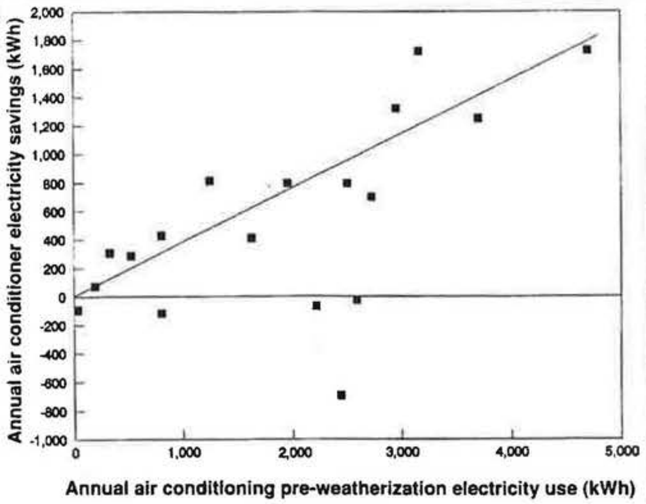


Figure 3. Comparison of normalized air conditioning electricity savings for the air conditioner replacement houses to their annual pre-weatherization air conditioning electricity consumptions. The solid line is a linear regression line for the measured data, excluding the three data points with pre-weatherization electricity consumptions of about 2,500 kWh per year and negative savings.

associated with high indoor temperatures. Studies are needed to further quantify the discomfort and health risks, understand the operating strategies of the window units before and after weatherization, and develop guidelines for addressing these issues. ■

*The publication of this article in **Home Energy** was underwritten in part by the U.S. Department of Energy's Office of Conservation and Renewables. The research was supported by DOE's Existing Buildings Efficiency Research Program. The article is based on the report "The Oklahoma Field Test: Air-Conditioning Electricity Savings From Standard Energy Conservation Measures, Radiant Barriers, and High-Efficiency Window Air Conditioners," Mark P. Ternes and William P. Levins. Office of Scientific and Technical Information P.O. Box 62, Oak Ridge, TN 378831. Tel: (615)576-8401. For more on the results and their implications, see "Alliance Issue Brief: Reducing Air Conditioning Use in Southern Weatherization Programs," Bion Howard and Mark Hopkins, Alliance to Save Energy, Washington, D.C., March 1993.*

Notes

1. The radiant barrier was tested in conjunction with at least R-19 attic insulation.
2. We did not evaluate energy savings by testing the simultaneous use of standard weatherization measures, radiant barriers, and air conditioner replacement.
3. Air conditioner installation costs would be significantly less if they were routinely installed under a weatherization program. For the field test houses, we estimated an average cost of $739 could be obtained once the measure is adopted program-wide.
4. The air conditioning electricity consumptions in the test houses was consistent with typical consumptions measured in low-income households in North Carolina. Other studies performed in more severe climates and involving larger, non-low-income houses cooled by central air conditioners, have measured higher annual consumptions of 4,000–10,000 kWh.
5. Average indoor temperatures were 1.1°F lower in the weatherization-only houses and 1.9°F lower in the radiant barrier houses after retrofit, but these changes were consistent with a 2.1°F decrease in average indoor temperature observed in the control houses. A milder summer the second year compared to the first is probably why indoor temperatures were lower, on average, the second summer.