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TECHNOLOGY'S ROLE IN HOME ENERGY CONSERVATION

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ABSTRACT

The technology of space-related advances in miniaturized electronics is being transferred to today's problems in residential energy monitoring. In addition, instrumentation techniques such as infrared scanning and gas leakage detection have been shown to translate into valuable analysis tools in a House Doctor Kit. Long term trends in future housing are viewed in the light of a "space capsule environment" in which air and energy needs are taken into careful account.

INTRODUCTION

In many ways my career could be simply summarized "from space to the cellar." Rocket engines were my prime concern for more than two decades extending through the early 70's. The fundamental problems of how to achieve stable combustion in engines consuming as much as 6,000 pounds of liquid propellant per second were the subject of research in industry, government and university laboratories.[1] Today, in sharp contrast my interests are concerned with fuel consumption of only a few pounds or less per hour. Rather than moving out into space, my sphere of research interest has moved into the heart of our living space — the home. The way in which these two seemingly unrelated areas share common technology is the topic of this paper.

MONITORING HOME ENERGY CONSUMPTION

The impact of miniaturized circuit components and printed circuit boards as a direct result of the U.S. space effort is evident throughout our daily lives. One only has to look closely at an indash auto stereo tape deck with AM/FM radio, all packaged in an unbelievably small space, to realize that today it is the mechanical space requirement for the cassette that dictates the final design, while the miniaturized electronics "fills in the nitches." This was certainly not the case in the past when the sizes of tubes and electronic components often would have ruled out the design altogether. These solid state electronic advances are now very evident in the world of energy conservation.

Although the unknowns of energy usage do not compare with the mysteries of space, the true energy savings potentials for residential retrofitting are only partially understood, even today. Confronted with the problem of placing small instrument packages in a series of homes to catalog and measure energy use, our research team immediately turned to solid state technology. Since we wanted to minimize field service problems we chose a four channel tape recording system that had survived the rigors of utilities field studies. However, three channels of data and one channel for time recording wasn't sufficient for our energy cataloging needs. Furthermore, we determined that readings once per hour were sufficient, rather than the 15-minute time segments that represented the utility recorder capabilities (15-minute segments are used to measure industrial energy demand which are often a prime factor in energy billing). The solution was to add auxilliary electronic circuits that would condition the incoming signals (convert the signals to forms that were usable to the recorder) and would multiplex the signals as well (in this case, four measurements would be handled in sequence on each channel). This multiplexing approach meant that up to 12 measurements could be made each hour (four quarter hour recordings for three channels) thus satisfying our home monitoring requirement. Table one illustrates the home energy features that were monitored in the Twin Rivers study.[2] Figure 1 illustrates the sensors used in the homes.

Who would provide the electronic expertise to design the equipment to meet this instrumentation requirement? I choose a student, a junior mechanical/aerospace engineer! I needed someone who would clearly define the needs of the individual channels from sensor to recorder. Nothing "shakes up" a mechanical engineering student more than imposing some complicated electronic requirement on his design. However, the development of space age electronics

TABLE 1

Channels monitored in the lightly-instrumented (Omnibus) townhouses

Channels 1 - 8 are recorded hourly, and channel 9 is recorded at 15 minute intervals.

1 Thermostat setting
2 Basement temperature
3 First-floor temperature
4 Second-floor temperature
5 Furnace on-time or air conditioner on-time
6 Electric water heater on-time
*7 Front door or front window open-time
*8 Back door or back window open-time
**9 Total electricity consumption

*The measurements of channels 7 and 8 were combined to channel 7, and the free channel 8 was assigned to attic temperature just prior to the 1976 winter.

**As the study progressed the need for additional attic temperatures and/or flow measurements became evident in certain homes. Four measurements then replaced the total electric consumption channel.

has removed much of the mystique from electronic circuit design. The integrated circuit chip performs a well-defined function. The engineer need only be precise in what he wants to achieve without becoming overly involved with how the solid state electronics are performing their task. With this in mind the student proceeded with the design* — 12 channels of input data conditioned and multiplexed onto three data recording channels.[3]

Figure 2 shows the circuit board designs with the components mounted. Since more than thirty gas-heated homes and ten heat pump heated/cooled homes were to receive the instrument package, the use of circuit boards was in order. This space-program-developed approach to wiring insures high reliability, and elimanates long hours of "hard wiring" the individual components. Much of the engineering talent was provided by our mechanical/aerospace student.

Using these energy monitoring packages, a number of important findings were made in the Twin Rivers[2] and Heat Pump projects.[4] For example:

- Even in modern housing there is a great potential for energy savings. Lowering air infiltration, and upgrading insulation on water heaters as well as adding to the insulation in the attic, resulted in 25% heating season energy savings that were demonstrated in the 30 gas-heated homes.[2,5] The savings are clearly shown in Fig.3 which also points out effects of conservation during the '73 oil crises.

- Savings as high as two thirds of the heating energy were achieved when high thermal resistance window shutters, basement wall insulation and further reductions in air infiltration were employed.[6]

- Heat pump space-conditioned homes were also found to fall short of full performance potential. Better controls, duct insulation and correct installation of the heat pump units were cited as areas of needed improvement. The efficiency of any heating system should be carefully checked if energy use is to be minimized. Ten percent improvements in gas or oil furnace efficiency normally translate into 15% energy savings.

- Summer energy use was found to be even more influenced by human thermal preferences than was winter heating.* Monitoring attic fans (as contrasted with whole house fans-the preferable way to go), with the 12 data channels primarily for attic temperature measurements, proved that little or no energy can be saved using attic fans if reasonable levels of insulation and ventilation are present in the attic.[7]

Before leaving the subject of on-site measurements, instrumentation for supplying weather information is also a necessity for any residential energy study. The use of integrated circuitry, the light emitting diode and optical switch-all developments of the space program-have allowed a modernization of weather instrumentation. Such items as integrated wind speed and trouble-free anemometers have been the result of such technology and were used in our bank rooftop weather station.[2]

THE HOUSE DOCTOR

The instrument package method of home energy monitoring, though important for research, cannot meet the overall requirement of auditing America's housing for energy consumption. For that task we propose the House Doctor approach. Instead of weeks of measurement, now the period of study is limited to a few hours. It is important to note that the technique often looks for energy consuming construction features that are rarely discussed.

There are a number of key instruments in the House Doctor Kit as shown in Fig. 4. Hopefully at some future date you, as an interested homeowner, would be able to rent the kit from a local tool rental shop, or borrow it from the Energy Extension Service. One very useful item in the kit is a hand-held infrared scanner. Clearly infrared probing in deep space as well as terrestial scanning has been a long-term interest of NASA. Now this space age device is needed to analyze the home.

Using the IR scanner within the house,** to scan walls, ceil-

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*In all fairness to the electrical engineering profession, the design was checked by an electronics engineer and careful attention was paid to the power requirements, and other operating data as stated in the individual component specification sheets.

*Double setback thermostats in winter showed savings of 18-40%, with no other changes to the house.[2]

**The IR scanner is three times as sensitive used inside rather than outside.

ings, and floors, one not only uncovers areas of poorly installed or missing insulation[8] but one also finds hidden bypass routes where warm air is leaving or cold air is entering the structure. These are not publicized air infiltration sites but rather flaws in the home design and/or construction. Examples are: shafts around plumbing vents and chimneys; gaps along the firewalls that separate townhouses; the areas above dropped ceilings; the area above the ceiling of the upper floor staircase; etc. Winter air exchange rates in American homes are approximately one exchange per hour, approximately 30-40% of house heating energy.

To emphasize these energy robbing bypasses we use another component of the House Doctor Kit. This device is referred to simply as the Blower Door. (See Fig. 4). Designed so as to expand to fit any normally-sized home entrance, the door contains a powerful blower which is capable of raising or lowering the interior pressure ± .2 inches of water (± 50 Pa) or more. As an example of another application solid-state electronics, the blower motor speed is fully adjustable. The RPM readout (that provides flow information) is accurate to one percent using a single integrated circuit "chip" with a small auxillary circuit. Currently this pressurization approach to house testing is being used coast-to-coast in research programs.[9-12] An important discovery through using this technique is that windows and doors represent only approximately 1/4 of the air infiltration loss story. Major improvements can often be made with minimum cost to the homeowner through attacking the more important bypass routes.

The Blower Door allows tightness comparisons between houses using a flow vs. inside-outside pressure graph as shown in Figure 5. The Swedish-American comparisons of tightness show our homes to be 3 to 4 times more leaky.[12] The sensitive pressure measurements can be made with a variety of gauges. The diaphragm gauge, developed in part as a result of low pressure space capsule requirements, can perform this task. This type pressure gauge provides the ability to measure details at the fluctuating pressure due to wind flow around a building.[11] Wind effects are an important feature of heat loss. Such pressure measurement techniques were useful in the detailed analysis of trees and their effect on residential energy consumption and the environmental impact of flow around cooling towers.[14] In the former type studies, wind tunnel modeling has also yielded correlations between weather and home energy consumption.[15,16]

Perhaps the most sophisticated approach to determining exactly how leaky our homes really are is the use of a tracer gas. An easily detectable gas is released in the home and samples are taken automatically,[17] or air is captured in sample bottles or bags[18] by the occupants every 1/2 hour for an hour or two. Gas concentration analysis makes use of equipment refined for leak detection in space program applications. The amount of tracer gas that is left in the home, as time progresses, provides the basis for obtaining the necessary data on house leakiness. Using the sample bottles you may be able to check out your house by sending the filled bottles to a lab for analysis to see whether your house is "breathing correctly."

FUTURE HOME DESIGNS

Up to this point we have discussed monitoring and detecting energy losses. The question might follow as to where we are heading in the design of homes of the future.

House designs that make full use of the earth as a refuge from the vagaries of the weather may appeal to some but I don't visualize a major trend toward the underground home. Rather the trend I see is that of removing weather influence through the use of high levels of insulation and a high degree of air tightness. Like the space capsule environment, this weatherized cocoon implies that a strict accounting of air and energy supplies is required. It must be recognized that minimum air flow needs to be carefully controlled to avoid moisture problems and/or indoor pollution. Heat exchangers are already in use in modern Scandinavian homes and in a limited number of American homes which allow recovery of 70% or more of the heat in the exhaust air while forced circulation provides the needed ventilation.[19]

When properly applied, this approach of high insulation and controlled ventilation can reduce heating demand to less than 20% of current house designs with a higher level of comfort.[19] The influences of weather are greatly reduced using this approach.

The remaining heat requirement may be provided by small, highly-efficient combustion heaters or solar collectors. One example of a new combustion system that is in the prototype stage is the pulse combustion furnace under development by the American Gas Association Laboratories and Lennox. This device works much like the V-1 rocket in that unsteady combustion pumps the combustion chamber and forces the flue gases out through an exhaust pipe no larger than that on a Chevette. No conventional chimney is necessary.

Early testing of this device for central heating indicates a seasonal performance of better than 95%.[20] This performance is contrasted with many current heating units operating in the 60% or lower range; this could mean a more than 50% improvement. Electrical heating systems such as multi-stage heat pumps are also moving to higher performance levels and offer stiff competition to combustion heaters.

Solar experiments have demonstrated an ability to generate electricity as well as heat[21]—clearly a direct follow on to earlier advances in space technology with solar cells. Economics of solar cell production is key to the success of this type of home design. At the other end of the solar spectrum is the passively-heated solar home. Here the influx of sunlight is controlled by appropriate window placement and heat retention is provided by the proper mass correctly placed within the structure.

Again this concept must remind us all of space capsules where the black side or the reflective side could effectively control the cabin temperature. Indeed the reflective mylar material developed and used in a variety of space applications is now reflecting additional sunlight into passive solar home windows or is being used as part of insulating shade systems to retain heat or to reflect unwanted summer sun.[22]

CONCLUSIONS

We have discussed a few examples of how space technology advances have aided today's residential energy conservation studies. In the years to come technology must continue to play a central role in conserving and generating our vital energy resources. Because the costs of energy were low in the past, we failed to do the creative thinking and planning needed to meet future energy demands. Now that the realization is finally dawning on many of us, it is reassuring to know that there is a wealth of basic technology, as well as methodology, provided to us by the space program which may be applied to energy challenges of the present and future. The challenge is there—much must be done to reduce the energy use in our homes, in our cars and in our businesses. We shouldn't settle for less than "landing on the moon."

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REFERENCES

1. Liquid Propellant Rocket Combustion Instability, Editors Harrje, D.T. & Reardon, F.H. National Aeronautics & Space Administration SP-194, 1972 (637p).

2. Energy and Buildings -- Special Princeton Issue, Vol 1 No 3 April, 1978, Elsevier Sequoia S.A. Lausanne, Switzerland.

   Saving Energy in the Home -- Editor Socolow, R.H., Ballinger Pub. Co. Cambridge, Mass., 1978.

3. Hall, S.A., and Harrje, D.T., "Instrumentation for the Omnibus Experiment in Home Energy Conservation," Princeton University Center for Environmental Studies Rpt. No 21, May 1975.

4. Harrje, D.T. "Heat Pump Performance Measured Using Ten Residential Units Operating in the Northeastern United States," Energy Use Management--Proceedings of the International Conference, Vol II, Ed. Fazzolare R.A. and Smith C.B., Pergamon N.Y., 1977.

5. Harrje, D.T., "Retrofitting, Plan, Action and Early Results Using the Townhouses at Twin Rivers," Princeton University Center for Environmental Studies Rpt. No. 29 (June 1976).

6. Sinden, F.S. "A Two-Thirds Reduction in the Space Heat Requirement of a Twin Rivers Townhouse," Energy and Buildings Vol 1, April, 1978, pp 243-260.

7. Dutt, G.S. and Harrje, D.T., "Forced Ventilation for Cooling Attics in Summer," presented at the Attic Ventilation Workshop sponsored by the National Bureau of Standards, July 1978.

8. Grot, R.A., Harrje D.T. and Johnson, L.C., "Application of Thermography for Evaluating Effectiveness of Retrofit Measures," Proceedings of the Third Biennial Infrared Information Exchange, AGA Corp., St. Louis, Missouri, 1976, pp 103-118.

9. Tamura, G.T., "Measurement of Air Leakage Characteristics of House Enclosures," ASHRAE TRANSACTIONS Vol 81, part 1, 1975, pp 202-211.

10. Caffe, G.E., "Residential Air Infiltration," ASHRAE TRANSACTIONS 1979, Vol 85, part 1.

11. Grimsrud, D.T., Sherman, M.H., Diamond, R.C., Condon, P.E., and Rosenfeld A.H. "Infiltration--Pressure Correlations: Detailed Measurements on a California House," ASHRAE TRANSACTIONS 1979, Vol 85, part 1.

12. Blomsterberg, A.K., and Harrje, D.T., "Approaches to Evaluation of Air Infiltration Energy Losses in Bldgs," ASHRAE TRANSACTIONS 1979, Vol 85, part 1.

13. Dutt, G.S. and Beyea, J., "Hidden Heat Losses in Attics—Their Detection and Reduction," Princeton University Center for Environmental Studies Report 77, Dec 1978.

14. Scanlan, R.H. and Sollenberger N.J., "Pressure Differences Across the Shell of a Hyperbolic Natural-Draft Cooling Tower," Wind Effects on Buildings and Structures--Proceedings of the Fourth International Conference, Cambridge Univ. Press, Cambridge, England, 1975, pp 143-149.

15. Mattingly, G.E. and Peters, E.F., "Wind and Trees—Air Infiltration Effects on Energy in Housing," Princeton University Center for Environmental Studies Report 20, 1975.

16. Buckley, C.E., Harrje, D.T., Knowlton, M.P. and Heisler, G.M. "The Optimum Use of Coniferous Trees in Reducing Home Energy Consumption," Princeton University Center for Environmental Studies Rpt. No. 71, May 1978.

17. Harrje, D.T. and Grot, R.A., "Automated Air Infiltration Measurements and Implications for Energy Conservation," Energy Use Management-Proceedings of the International Conference, Vol. 2, Pergamon, New York, 1977.

18. Grot, R.A., A Low Cost Method for Measuring Air Infiltration Rates in Large Sample of Dwellings," Symposium of the ASTM Symposium of Air Infiltration and Air Exchange Rate Measurement, Washington, D.C., March 78.

19. Korsgaad, V., Zero-Energy House, Technical University of Denmark, ERDA publication NP-22388, Sept. 1977.

20. Hollowell, G.T., "Efficiency of Gas-Fired Appliances," American Gas Association Laboratories, Cleveland, Ohio, 1976.

21. Solar One — University of Delaware, Newark, Del. Institute of Energy Conversion.

22. Hand, A.J., "Insulating Window Shade--Ups the R-Value to 15 or More," Popular Science, Vol 214, No 1, Jan 1979 (pp. 74-79, 150).

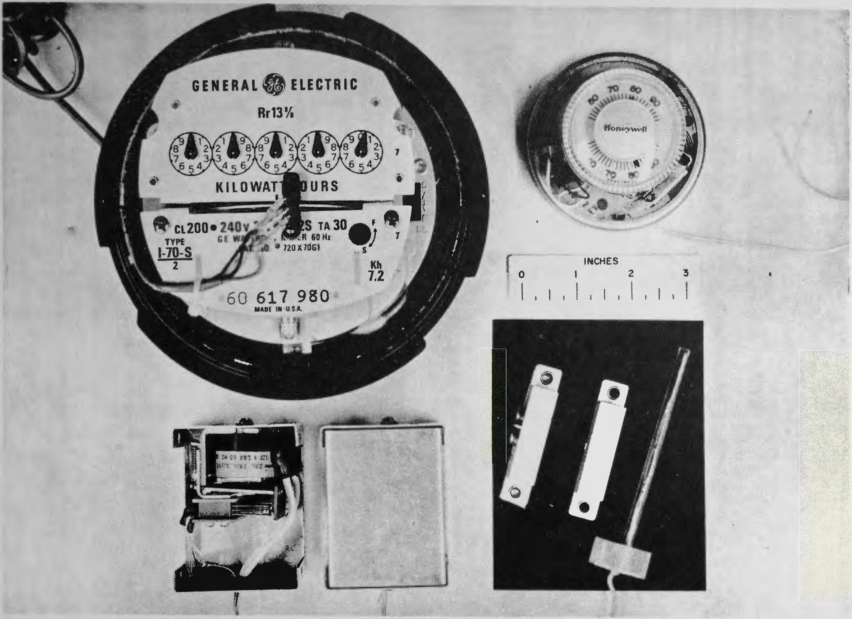
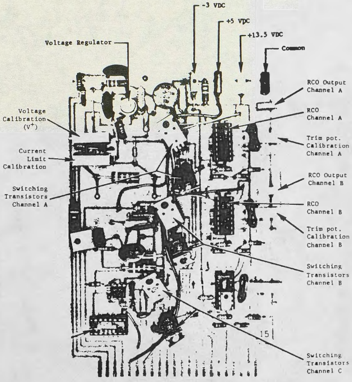
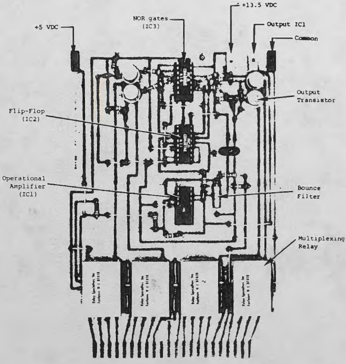


Figure 1. Sensors. Clockwise from Upper Left: Adapted Watt-Hour Meter, Adapted Thermostat, Thermistor, Magnetic Switches, Duel Water-Heater Relays.



Board No. 1



Board No. 2

Figure 2. Data Converter/Multiplexer with Printed Circuit Boards in Place.

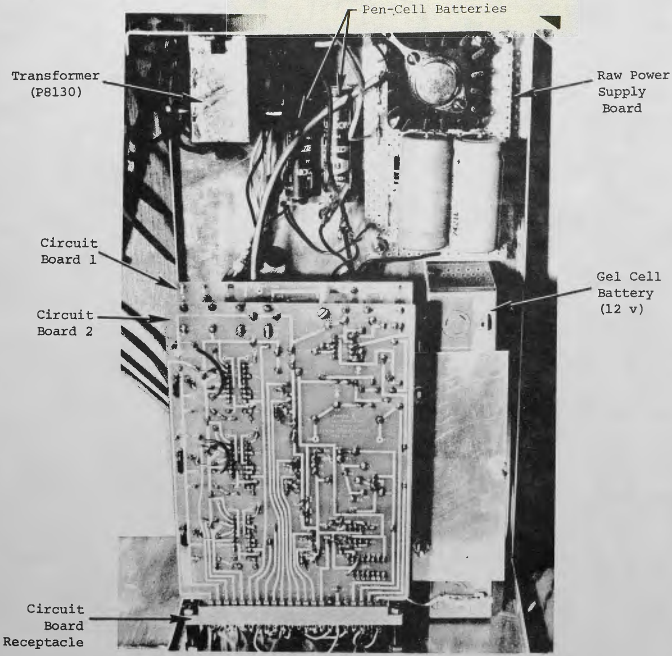


Figure 2 Continued. Data Converter/Multiplexer with Printed Circuit Boards in Place.

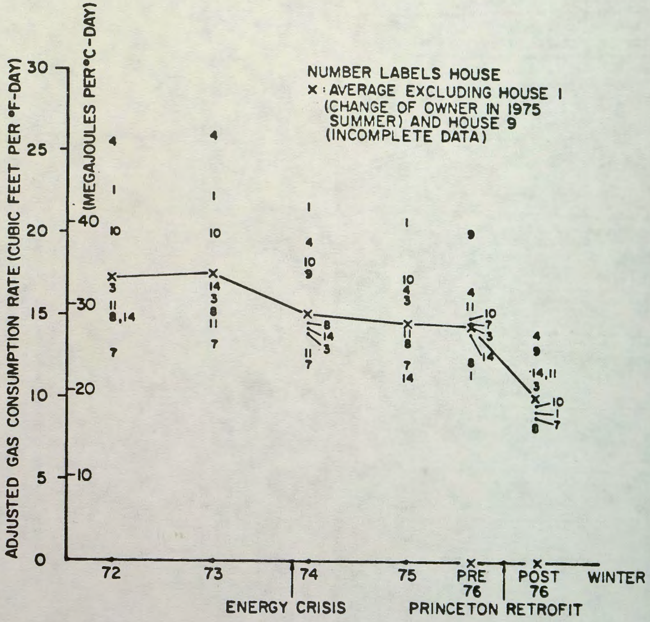


Figure 3. 5 Year History of Nine Omnibus Houses Fully Retrofitted by Princeton in Winter 76.

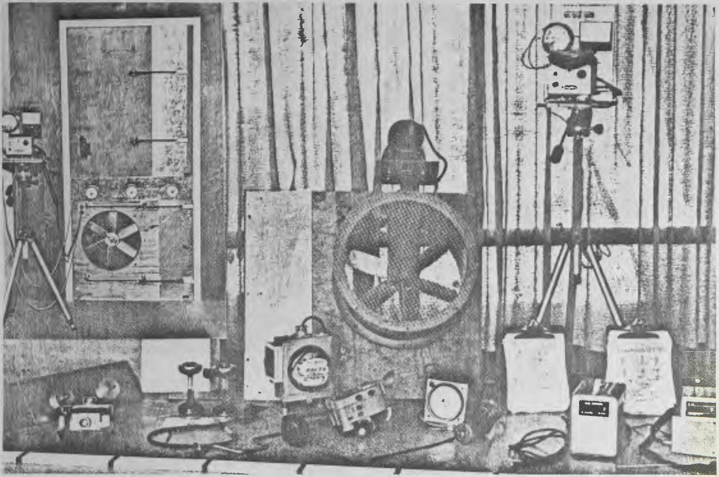


Figure 4. Equipment Used for Energy Audit — Blower Door Shown in Insert.

The Equipment includes from left to right: camera and measuring stick for rapid outside house dimensions, furnace gas sampling kit, electric meter for appliance performance, hand-held infrared scanner, the lower portion of the blower/door (also shown in insert), control for blower door, data pads, temperature probes (a.c. and battery versions).

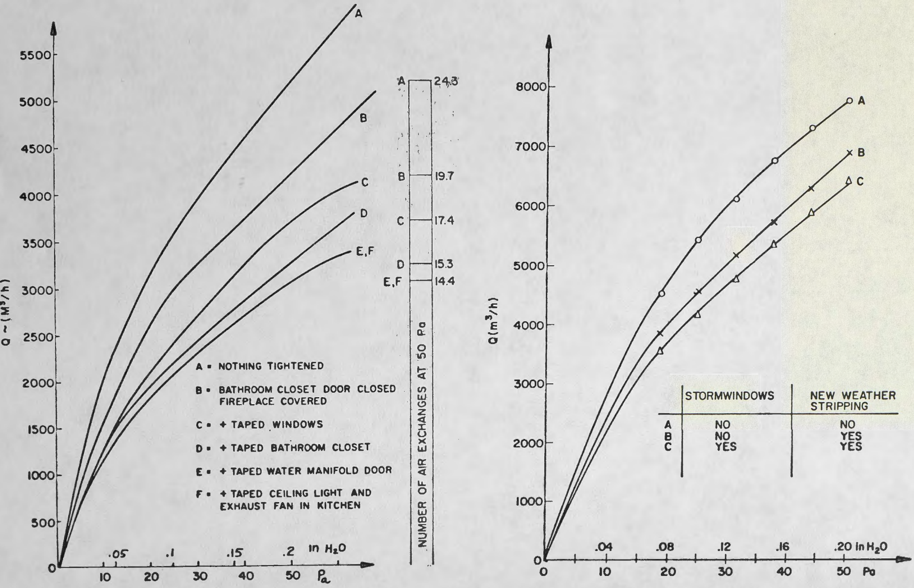


Figure 5. Flow Rate of Air Using the Blower Door for a Range of Inside Outside Pressures for Two Dwellings - Note the Reduction as Changes Are Made.