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ENERGY CONSERVATION, AIR QUALITY, HEALTH, AND HOUSING SATISFACTION

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ABSTRACT

Regression analysis of survey data from 169 households in central Iowa is used to analyze the effect of residential energy conservation measures on air quality in the residence, the health of the residents, and satisfaction with the dwelling. It was found that "tightening up" houses to make them more energy-efficient has a deleterious effect on the air quality when unvented kerosene space heaters are used and when there are smokers in the household. However, the effect on the health of the residents is small except for the households where there are smokers. While air quality has little effect on residents' satisfaction with the dwelling, satisfaction is positively affected by the presence of energy-conserving measures and negatively affected by illness.

PURPOSE

The purpose of this paper is to examine some of the consequences of residential energy conservation measures that are taken by families. The consequences under study include the quality of the air in the home and its effect on the health of the residents. The purpose is accomplished through the analysis of social survey data gathered in Iowa during the winter of 1981-1982.

BACKGROUND OF THE STUDY

Because making dwellings more energy efficient tends to be cost effective, many households are adopting energy-conserving measures. The quality of the indoor air, however, may be adversely affected by some energy-conserving features that reduce the infiltration of outside air into the dwelling. Levels of carbon monoxide in the home may be elevated because dilution by outside air is required to lower carbon monoxide concentrations inside the house. In contrast to some other gases, the probability of finding measurable amounts of carbon monoxide in 'normal' houses is high enough to permit reliable statistical analysis of a modest sized sample.

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Although there are standards for maximum allowable rates of carbon monoxide exposure in occupational settings, standards for dwellings do not exist. The American Conference of Governmental and Industrial Hygienists developed threshold limit values (TLV) for potentially hazardous gases in the workplace (American Conference of Governmental Industrial Hygienists, 1980). These are time-weighted averages of the gas for a normal 8-hour workday or 40-hour workweek. The TLV for carbon monoxide is 50 ppm. The Ambient Air Quality Standard for carbon monoxide is 9 ppm. This outdoor standard is sometimes used as the standard for air quality in the home.

Exposure to low levels of carbon monoxide causes such symptoms as headaches, nausea, weakness, dizziness, and mental depression (Amiro, 1969). Carbon monoxide combines with hemoglobin at a rate much higher than that of oxygen and, thereby, displaces the oxygen in the bloodstream. Carboxyhemoglobin deprives the vital organs of the oxygen they need to sustain life (Amiro, 1969). The Surgeon General (U.S. Department of Health, Education and Welfare, 1979) reports concern over the health of occupants due to the sealing of buildings to make them more airtight for energy efficiency and use of air filtration and recirculation rather than ventilation.

The addition of caulking, weatherstripping, storm doors and storm windows can reduce air infiltration from the outside and air exfiltration from the indoor environment. It is desirable, for energy conservation, to reduce the exchange of outside air for inside air. The inside air has been heated or cooled, and the infiltration of outside air increases the amount of energy needed to keep the temperature inside the house constant.

It is estimated that 25 to 50 percent of energy consumption for residential heating is the result of infiltration (Stolwijk, 1981). Homeowners can reduce infiltration by up to 25 percent with weatherstripping and caulking (Stolwijk, 1981). Natural and mechanical ventilation methods can be used to regulate the air exchange rate, but these methods typically exchange unheated (or uncooled) air for heated (or cooled) air.

Lowered air exchange rates have been shown to have a strong inverse relationship with the level of gases in the indoor air (Hollowell and Traynor, 1978). Gases and particulates generated within the dwelling are not diluted as quickly by outside air when the air exchange rate in a dwelling is reduced. Reduced air quality produced by combustion in gas appliances, spaceheaters, and smoking is investigated in this paper with a view to understanding the effects on health from sources of potentially hazardous levels of carbon monoxide.

Gas appliances Elevated levels of carbon monoxide and nitrogen dioxide in homes with gas cooking appliances have been found (Melia, Florey, Darby, Palmes, and Goldstein, 1978; Sterling and Sterling, 1979). However, operating a gas oven in rooms with known air exchange rates produced levels of carbon monoxide that exceeded one-hour air-quality standards only when the room had a very low exchange rate, 0.24 air exchanges per hour (Hollowell and Traynor, 1978).

Somewhat inconsistent results have been found about the effect of combustion emissions from household appliances on health. Melia, Florey, Altman, and Swan (1977) found that children in homes with gas cooking stoves have significantly more respiratory illnesses than do children in homes with electric cooking appliances. Keller, Lanese, Mitchell, and Cote (1979) find no relationship between gas cooking stoves and health.

Smoking That smoking causes ill health for the smoker is well documented (U.S. Department of Health, Education and Welfare, 1979). Bonham and Wilson (1981) found that children in homes with smokers experience significantly more days of ill health due to respiratory diseases than do children in homes of nonsmokers. Hirayama (1981) reports that wives of smokers have a higher risk of developing lung cancer than do wives of nonsmokers. The smoking of cigarettes in an enclosed space produces elevated levels of carbon monoxide.

Space heaters Unvented gas or kerosene space heaters present potential air quality hazards. Tests performed on unvented kerosene heaters indicate that emissions of carbon dioxide and nitrogen dioxide require ventilation rates greater than the average rates in homes to prevent concentrations from exceeding recommended ambient air quality levels (Woods, 1981). Carbon monoxide emissions required only 0.6 air changes per hour to control the concentration, but calculations show that a ventilation rate that low would result in carbon dioxide and nitrogen dioxide concentrations that would present health risks to the residents.

Dwelling size The air quality problem may have been compounded in recent years because of economic problems in the home construction industry. Since 1979, builders have been building smaller homes to make new construction more affordable. The volume of the house may have some effect on the concentration of air pollutants inside the house. Other things being equal, the smaller house has a higher probability of a high concentration of gases than does a larger house. The smaller dwelling typically has the same or a similar number of sources of gases as does the larger dwelling, heating, cooking, and water heating devices.

THEORETICAL MODEL

The approach used in this paper is based on the scientific literature focused on the study of families and their interaction with their environments. A model that draws together some of the social, physical, and biological aspects has been applied.

This paper is unique because household constraints (the size of the dwelling, the energy-conservation features of the dwelling, the concentration of gases in the dwelling, the health symptoms of the residents and the residents' satisfaction with their housing) are included. The approach, adapted from the housing adjustment model by Morris and Winter (1978), is shown in Figure 1. The causal relationships included in the analysis are shown in Figure 1 among household constraints, dwelling size, combustion sources, energy-conserving features, quality of the air, and the resultant health symptoms and housing satisfaction.

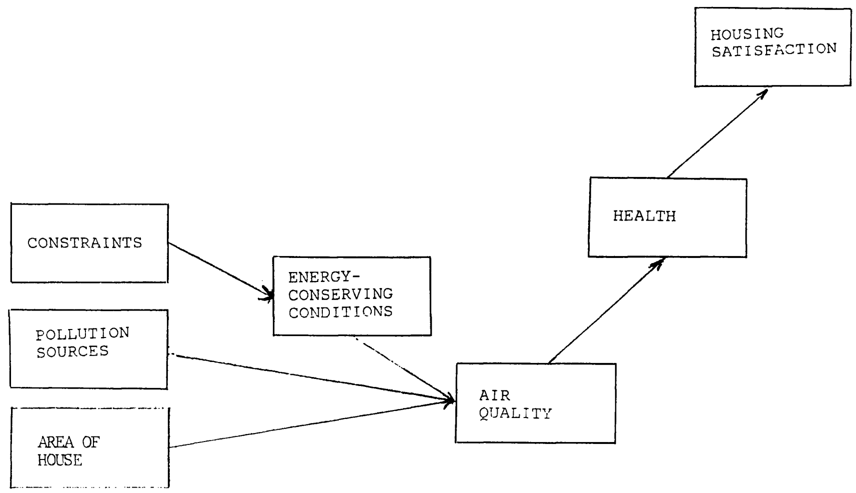

FIGURE 1. Theoretical model

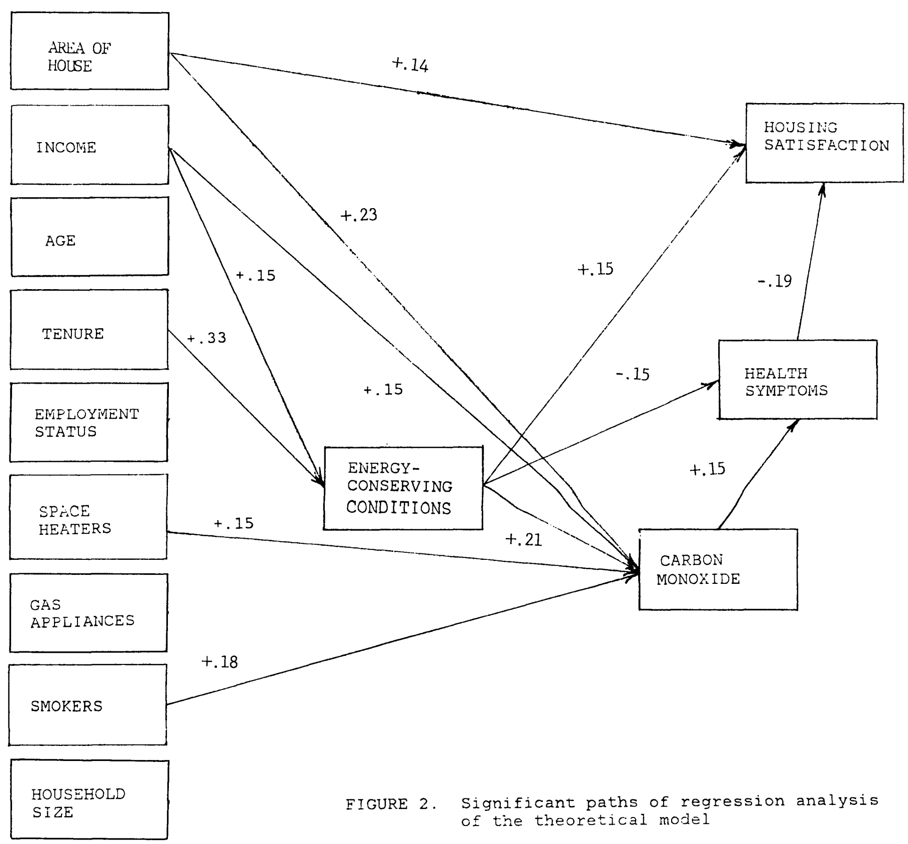

FIGURE 2. Significant paths of regression analysis of the theoretical model

DEFINITIONS OF THE VARIABLES AND HYPOTHESES

Constraint variables Constraints are the "factors that restrict a family's ability to engage in housing adjustment behavior" (Morris and Winter, 1978). Age, tenure (own or rent), and income are indicators of those constraints. Older residents may have health problems that prevent them from maintaining energy-efficient homes. Research shows that older residents report satisfaction with their dwellings even when conditions would seem not to warrant it (Morris & Winter, 1978). They may, therefore, be less open to making energy-conserving adjustments to their housing. Residents who have lower incomes may find it difficult to maintain their homes and make them energy conserving. Renters may be less able than owners to alter their dwelling to be energy-conserving. Because these are constraining factors, it is hypothesized that there is a negative relationship between age and income and the energy-conserving features of the house and a positive relationship between ownership and energy-efficient dwellings. Other constraint variables that may affect the endogenous variables are household size and employment status.

Age of the household head is recorded in years. Employment status of the head of the household is coded 1 working and 0 not working. Home ownership is coded 0 for renters and 1 for owners. Income is the number of dollars taken in by the household last year. Household size is the number of persons currently living in the household. The average age of the household head is 51 years and 67 percent of the household heads are employed. The mean income of the households is $23,997 and the mean household size is 2.96 members. Eighty-two percent are owners.

Energy-conserving features The energy-conserving features of interest in this study are those that contribute to the energy efficiency of the house; i.e., they tend to restrict infiltration. The selected energy-conserving features of the house are hypothesized to contribute to the concentration of the potentially hazardous gases by impeding their dilution and exfiltration. Respondents were asked if the following features were present in their dwelling: double-pane or storm windows and doors; weatherstripping and caulking on most doors and windows; more than four inches of ceiling insulation; floor and wall insulation; vapor barriers; foundation and band joist area insulation.

Energy-conserving conditions were coded as dummy variables: 0 for not present, 1 for present. When missing values were less than 10 percent of the total, they were recoded to the mode. If the missing values were greater than 10 percent of the total, which was true for vapor barriers and band joist insulation, the missing values were recoded as being present in houses built in 1960 or after, and not present in houses built before 1960. An energy-conserving scale was created by adding together the features that augment the energy-efficiency of the house. The range is 1 to 9, with a mean of 5.7.

Storm doors and windows were present in 88 percent of the houses. Caulking and weatherstripping around doors were reported in 80 percent of the dwellings and around windows in 79 percent of the residences. More than four inches of ceiling insulation was reported in 76 percent of the houses, wall insulation in 83 percent, and floor insulation in 72 percent. A vapor barrier was reported in 26 percent of the dwellings, foundation insulation in 28 percent, and band joist area insulation in 20 percent.

Dwelling size The data in this study do not include volume of house, but do include area of floor space. The range of size of the area is from 300 square feet to 3600 square feet. The mean is 1330; the median, 1200; and the mode, 1064. There are eight cases with missing data. Because it is known that many of these missing cases are apartments, they were coded to the mode.

Combustion sources The sources of potentially hazardous gases studied are gas appliances, gas and kerosene space heaters, and cigarette smoking. The gas appliances included in the analysis are cooking stoves, water heaters, clothes dryers, and furnaces.

The following percentages of homes reported using gas appliances: gas cooking stoves, 42 percent; gas water heaters, 87 percent; gas dryers, 33 percent; gas furnaces, 94 percent. Adding together the number of gas appliances in the dwelling, 12 percent had one appliance, 36 percent had two, and 52 percent had three. Kerosene or gas space heaters were present in eight percent of the households. One or more smokers were reported in 48 percent of the dwellings; 11 percent had two or more smokers.

Air quality Air quality is conceptualized as the level of potentially hazardous gases in the home. The gas measured was carbon monoxide, a product of incomplete combustion.

Measuring the concentration of carbon monoxide in the dwelling was accomplished with a Drager gas detector pump. The Drager gas detector consists of two parts: a bellows pump and a tube for testing a particular gas. The pump is hand operated by squeezing the bellows. The volume of air supplied with each stroke is 100 cubic centimeters. As the air passes through the tube to the bellows, the gas being tested reacts chemically with the contents of the tube, changing the color of the tube contents. Each tube is calibrated so that when the required number of strokes have been taken, an immediate reading of the concentration can be made by the observer.

The Drager carbon monoxide "5/c" tube is used to measure the level of carbon monoxide. It measures levels from 5 to 150 ppm. The relative standard deviation is 10 to 15 percent. When a reading of less than 5 ppm was obtained, the interviewer was instructed to interpolate the reading, so accuracy may have been lost at readings of less than 5 ppm. Forty-nine percent of the houses had no carbon monoxide. Forty-five percent had readings of from 1 to 5 ppm. The remaining 6 percent of the houses had a range of 6 ppm to 11 ppm. Five houses had levels above the outdoor standard of 9 ppm.

The hypotheses about the relationships among the combustion sources, the energy-conserving features of the house, and the concentration of carbon monoxide are:

1. Gas and kerosene space heaters, gas appliances, and cigarette smoking produce higher concentrations of carbon monoxide in the residences.
2. The more energy-conserving the dwelling, in terms of

structural conditions, the higher is the level of carbon monoxide in the dwelling.
3. The smaller the dwelling, the higher the level of carbon monoxide.

Health effects The physiological effects of exposure to carbon monoxide at very high levels are well documented. The hypothesis to be tested is that relatively low-level, long-term exposure to carbon monoxide has a deleterious effect on the health of residents. The health of the residents was measured by asking if anyone in the household had any of a list of symptoms. The symptoms included those that are caused by carbon monoxide poisoning, reactions to smoke, and respiratory illnesses. A scale was created by coding 0 for no and 1 for yes if anyone in the household had a symptom and adding each of those responses together. The symptoms included in the scale are running nose, eyes that often burn, eyes that often water, nose that burns, frequent colds, rash or skin irritation, trouble breathing, frequent sore throats, frequent headaches, frequent coughing, frequent tiredness, bronchitis, and asthma. The range of the scale is 0 to 10. Six cases were removed from the sample because of known chronic illness such as asthma and emphysema.

Housing satisfaction Morris and Winter (1978) define housing satisfaction as "a state of the level of contentment with current housing conditions." In the Morris and Winter model, housing satisfaction is directly affected by housing deficits. Housing deficits certainly include poor air quality in the home. Further, some residents experience physiological problems, such as respiratory diseases, that they do not associate with elevated levels of gases from the appliances in their homes. They may not even be aware of an air quality problem in their home. Therefore, they would not express dissatisfaction with their housing environment based on the air quality. So the deficit itself is not hypothesized to affect satisfaction in this model. Poor health, on the other hand, may cause dissatisfaction with the overall life situation. Dissatisfaction with housing is hypothesized to be one component of general dissatisfaction resulting from poor health. Constraints may prevent families from overcoming deficits, thus contributing to dissatisfaction.

Satisfaction with the dwelling was measured by using a Likert-type scale. One item was used: "In general, how satisfied or dissatisfied are you with your housing?" The responses ranged from (1) extremely dissatisfied to (7) extremely satisfied. Seventy-nine percent reported being either satisfied or extremely satisfied.

THE SAMPLE

The data were gathered in the winter of 1981-82 by trained interviewers between November 15, 1981, and March 15, 1982. Households were sampled in the five largest communities of the nine-county Fort Dodge, Iowa Extension Area. Those communities are Fort Dodge, Boone, Carroll, Webster City, and Humboldt/Dakota City.

Interviews were obtained from an adult in each household. The level of carbon monoxide was measured in each household at the end of the interview. Three hundred households were selected by using systematic random sampling from the telephone directories of the five communities. Completed interviews were obtained in 198 households for a response rate of 66 percent. The sample size was reduced to 173 because 19 interviews had missing or inconsistent data and 6 cases had chronic illnesses as noted.

THE ANALYSIS

The relationships are tested by using hierarchical regression, with the exception of the regression of energy-conserving conditions in which all the exogenous variables are entered at once. In the hierarchical regressions, the variable hypothesized to have a direct effect on the dependent variable is entered into the regression first. Variables that have indirect effects are entered into the regression in the order in which they are related to the dependent variable according to the model (Figure 1). The final step in each regression of a dependent variable includes all the independent variables.

Energy-conserving conditions Evaluating the theoretical model from left to right, the first dependent variable to be tested is the energy-conserving conditions. Table 1 shows the effects of the constraint variables on the energy-conserving housing conditions. The group of variables explains 17 percent of the variance in the existence of energy-conserving housing conditions. Ownership accounts for most of the variance (Beta=0.33), and income contributes significantly (Beta= -0.15).

Table 1. Regression analysis of energy-conserving conditions

Variables		Beta	t
Constraint variables			
Age		.06	0.61
Income		.15	1.97*
Household size		-.05	-0.60
Employment status		.06	0.67
Homeownership		.33	4.23*
R^2	.17		
Adj. R^2	.15		
F	6.95*		
d.f.	5/168		

*Significant p< 0.10

The hypothesis that owners and higher-income households have more energy-conserving housing features than renters or lower-income households is well supported. That older households have fewer energy-conserving conditions than younger households is not supported in this analysis. Neither size of household nor employment status has a significant effect on the energy conditions of the house.

Carbon monoxide To evaluate the effects of the exogenous variables on the levels of carbon monoxide, hierarchical regression is used. The results are presented in Table 2. Combustion sources are entered into the model first. As a group, they account for 5.5 percent of the variance in carbon monoxide concentrations. The presence of gas or kerosene space heaters and the number of smokers contribute similar amounts to the explained variance (Beta=0.15). The number of gas appliances is not a significant determinant.

Table 2. Hierarchical regression analysis of carbon monoxide

Variables	Step 1		Step 2		Step 3	
	Beta	t	Beta	t	Beta	t
Pollution sources						
Gas appliances	.10	1.32	.11	1.44	.04	1.58
Space heaters	.15	2.00*	.12	1.59	.15	2.02*
Smokers	.15	1.97*	.16	2.13*	.18	2.43*
Energy-conserving conditions			.14	1.88*	.21	2.65*
Constraint variables						
Age					.04	0.43
Income					-.15	-1.80*
Household size					.13	1.47
Employment status					.00	-0.02
Homeownership					-.01	-0.13
Area of House					-.23	-2.76*
R^2	.055		.075		.150	
Adj. R^2	.038		.053		.100	
F	3.34*		3.42*		2.98*	
d.f.	3/170		4/169		10/163	

*Significant $p < 0.10$

In the second step of the regression analysis, the energy-conserving conditions are entered with the combustion sources. The explained variance increases to 7.5 percent. With the addition of the energy-conserving conditions, gas or kerosene space heaters' contribution to the variance is decreased slightly and is not significant at the .10 level. Energy-conserving conditions are a significant determinant of air quality (Beta=0.14).

In the third step, the constraint variables and dwelling size are added to the equation. The explained variance increases to 15 percent. Household income is the only constraint variable that is a significant determinant of carbon monoxide (Beta=-0.15). Area of the house is the strongest predictor of carbon monoxide (Beta=-0.23). The contribution of smokers and energy-conserving conditions is somewhat higher than in the previous regression (Beta=0.18 and 0.21). The relationship between income and the level of carbon monoxide is somewhat complex. The zero-order correlations indicate a positive relationship exists between area of the house and income and a negative relationship between the use of space heaters and income. So the negative effect of income on the concentration of carbon monoxide may be due to these factors (larger houses and little use of space heaters). This is counter to the expected positive relationship that would be due to low-income households' having fewer energy-conserving conditions.

The regression analysis supports the hypotheses that the number of smokers and the presence of combustion space heaters in the home contribute to higher levels of carbon monoxide. The hypothesis that the number of gas appliances in the home cause greater amounts of carbon monoxide is not well supported. The hypotheses that smaller homes and homes with more energy-conserving conditions have higher concentrations of carbon monoxide are supported in this analysis.

Symptoms of ill health Table 3 presents the regression analysis of the reported number of symptoms on the independent variables. Carbon monoxide is entered first in the solution. Although it explains only 2 percent of the variance in the number of symptoms, it is a statistically significant determinant.

In step two, the combustion sources are entered. The explained variance increases to 4.6 percent, but carbon monoxide is not a significant predictor in this step. The number of smokers in the household is the most significant variable in this step of the equation (Beta=0.15). When energy-conserving conditions are entered in step 3, carbon monoxide again has a significant effect on the number of health symptoms (Beta=0.14). The number of smokers continues to be significant, although slightly lower (Beta=0.13). The energy-conserving conditions have a significant negative relationship with the number of health symptoms (Beta=-0.13). The amount of explained variance is 6 percent.

In step 4, the constraint variables and area of the house are added. As a group, they increase the proportion of explained variance to 9 percent, but this is not enough to be significant inasmuch as the F-ratio drops to 1.51. None of the constraint variables make a significant direct contribution to health.

Carbon monoxide and the number of energy-conserving conditions are the only variables that have significant effects on health. Because the constraint variables do not increase the explained variance significantly, the variables that have the best explanatory effect on health in the theoretical model are those included in step 3 in that regression. Smoking is a significant determinant of health in that step.

The regression analysis of health symptoms would seem to support a rather weak causal relationship between carbon monoxide and health symptoms. This is not surprising, given the relatively low concentrations of carbon monoxide found in the homes.

Table 3. Hierarchical regression analysis of health symptoms

Variables	Step 1 Beta	t	Step 2 Beta	t	Step 3 Beta	t	Step 4 Beta	t
Carbon monoxide	.14	1.91*	.12	1.56	.14	1.79*	.15	1.87*
Pollution sources								
Gas appliances			-.05	-.069	-.06	-0.81	-.07	-1.00
Space heaters			.03	0.44	.06	0.74	.05	0.62
Smokers			.15	1.94*	.13	1.76*	.09	1.14
Energy-conserving conditions					-.13	-1.68*	-.15	-1.79*
Constraint variables								
Age							-.05	-0.48
Income							-.07	-0.86
Household size							.10	1.08
Employment status							-.06	-0.62
Homeownership							.05	0.56
Area of House							.11	1.27
R^2	.021		.046		.062		.090	
Adj. R^2	.015		.023		.034		.031	
F	3.63*		2.03*		2.20*		1.51	
d.f.	1/172		4/169		5/168		11/162	

*Significant p< 0.10

The hypothesis that the number of smokers in the home affects health is supported, but the relationship is a weak one. It is somewhat surprising that none of the constraint variables have any effect on health. The energy-conserving conditions make both a direct and an indirect contribution to health symptoms. The indirect effect through carbon monoxide is positive, indicating that houses that are very energy conserving are trapping carbon monoxide and having a deleterious effect on health. The direct effect is an indication that some energy-conserving conditions may be keeping out drafts and having other effects, thus decreasing the number of health symptoms.

Housing satisfaction Table 4 presents the regression analysis of residents' satisfaction with housing on the independent variables. Health symptoms are entered in step 1. They explain almost 6 percent of the variance in satisfaction with the causal effect being negative (Beta=-0.24). When carbon monoxide is entered into the equation in step 2, little change is made in the explained variance, and its effect is not significant (Beta=-0.11).

Combustion sources are entered in step 3 and they make almost no change in the explained variance. None of the sources is a significant determinant of housing satisfaction. In step 4, the energy-conserving conditions are entered into the equation. The amount of explained variance in housing satisfaction increases to 11.6 percent. Health symptoms is a significant determinant (Beta=-0.19) with energy-conserving conditions (Beta=0.22). The energy-conserving conditions acts as a suppressor with this group of variables since it raises the contribution of carbon monoxide to a significant level (Beta=-0.15).

The constraint variables and the size of the dwelling are entered into the equation in step 5. The amount of explained variance increases to 20 percent. The area of the house is a significant determinant of housing satisfaction, as well as health symptoms and energy-conserving conditions. None of the constraint variables are significant predictors of satisfaction. Carbon monoxide drops out as a significant predictor.

It is not surprising that poor health results in decreased satisfaction with housing. The "level of contentment" with almost any aspect of life is diminished by poor health. With respect to concerns about declining energy resources, it is encouraging to find that satisfaction with housing is enhanced by the presence of energy-conserving features. The analysis indicates that residents of larger homes are also more satisfied with their dwellings.

DISCUSSION

The theoretical model is supported because most of the hypothesized direct effects are well supported. The significant relationships from the test of the theoretical model are presented in Figure 2. The betas are included from the final step of the regressions of the theoretical model.

Although many of the hypotheses are supported by the analysis, not all of the relationships are strong enough to warrant definitive conclusions about the effect of energy conservation on air quality. As hypothesized, home owners and higher-income households have more energy-conserving features in their homes. This supports the literature regarding the effect of constraints on the ability of households to upgrade their housing. Age, household size, and employment status did not act as constraints in this analysis.

Gas and kerosene space heaters and cigarette smoking raise the concentrations of carbon monoxide in the home. The number of other gas appliances does not contribute significantly to the level of carbon monoxide, presumably because the major appliances, gas furnaces and water heaters, are ventilated to the outside. Unvented space heaters and cigarette smoking emit carbon monoxide into the indoor space where it must be diluted by outside air to reduce concentrations.

Table 4. Hierarchical regression analysis of satisfaction with housing

	Step 1 Beta	Step 1 t	Step 2 Beta	Step 2 t	Step 3 Beta	Step 3 t	Step 4 Beta	Step 4 t	Step 5 Beta	Step 5 t
Symptoms	-.24	-3.21*	-.22	-2.97*	-.22	-2.86*	-.19	-2.52*	-.19	-2.57*
Carbon monoxide			-.11	-1.53	-.12	-1.52	-.15	-2.00*	-.08	-1.14
Pollution sources										
Gas appliances					.02	0.34	.04	0.59	.09	0.99
Space heaters					.03	0.36	-.01	-0.18	-.07	-0.94
Smokers					-.02	-0.32	-.00	-0.08	.01	0.09
Energy-conserving conditions							.22	2.92*	.15	1.81*
Constraint variables										
Age									.11	1.81
Income									.13	1.53
Household size									-.10	-1.15
Employment status									-.08	-0.84
Homeownership									-.04	-0.44
Area of House									.14	1.67*
R^2	.057		.069		.071		.116		.200	
Adj. R^2	.051		.058		.043		.084		.138	
F	10.32*		6.37*		2.57*		3.66*		3.30*	
df	1/172		2/171		5/168		6/167		12/161	

*Significant $p < 0.10$

Smaller dwellings and dwellings with more energy-conserving features also have higher levels of carbon monoxide. These relationships are not strong, however. This may be due to the some error in the reporting of the respondents about the features of their houses. There seems, however, to be some lowering of the air-exchange rate in houses with more energy-conserving features that trap carbon monoxide in the houses resulting in elevated concentrations.

Smokers in the household and elevated levels of carbon monoxide have small, but deleterious, effects on the health of the residents. In general, this confirms the research of others on the negative effects of cigarette smoking on health. The regression indicates that some of the effect of carbon monoxide on health is due to smoking. That is, smokers have more carbon monoxide in their homes, but the health effects may be more directly related to smoking than to carbon monoxide levels.

Whereas residents who have larger houses, higher incomes, and more energy-conserving features are more satisfied with their housing, respondents with health problems are less satisfied. The supposition is that poor health results in lowered satisfaction with the quality of life and housing is one of the components of one's general life situation. The actual deficit, in this case poor air quality, does not have a direct effect on satisfaction with housing. Presumably, the level of air quality is not perceived as poor and not salient to the resident.

The implications of the findings are cause for concern. While the citizenry is being encouraged to make their housing more energy conserving, the consequences are not well-documented. This study and the ones cited indicate that the air quality in the home may be adversely affected, particularly in homes with unvented combustion sources. The effects on the health of occupants in 'normal' dwellings, however, are not well-understood. Although technology can provide some solutions in the form of air-to-air heat exchangers and the introduction of outside air into the return air system, these solutions can add considerably to the cost of 'tightening up' a house. It is not yet clear whether consumers need to make these investments when they make their houses more energy-conserving, but the possibility should not be overlooked.

The problem is compounded by the harsh economic realities of purchasing a home. While residents with larger homes are more satisfied with their dwelling, builders are constructing smaller homes to fit the budgets of consumers who are being squeezed by high interest rates. This analysis indicates that smaller homes may have more air quality problems than larger homes if there are smokers in the home or if unvented space heaters are used. Although consumers may be able to save both money and energy with smaller homes, they must be cautious about the effect of their activities in the home on their environment and their health.

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