Optimizing thermal insulation and ground levels in residential wall construction : an economic analysis
by Clifford Walter Nixon

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Applied Economics
Montana State University

Abstract:
The purpose of the study was to identify cost minimizing thermal wall designs in residential buildings by the two fold approach of determining optimal insulation levels and utilizing the effectiveness of the ground as a thermal barrier. To approach the problem cost and savings functions were defined to simulate the experimental wall's structural and thermal characteristics. Insulated wall structures up to 20 inches thick were examined so costs resulting from each change in insulation level within the wall reflected any additional expenditures necessitated by thickened wall designs. The savings generated by each additional level of insulation were estimated by engineering procedures recommended by the American Society of Heating, Refrigerating and Air-Conditioning Engineers. When net savings from insulation and wall grounding were optimized together, a provision was made in the mathematical model to place the walls deeper in the ground in steps of 10 percent of the total wall height. Such an approach defined a systematic manner of examining the use of the ground as a thermal barrier. Fuel savings resulting from applications of wall insulation were distinguished from those attributable to the placement of the wall in relation to the ground level in the following way: Reductions in heat flow across any section of the model home's thermal envelope which resulted as successive insulation levels were applied to that portion of the wall, were attributed to the thermal insulation. In contrast, savings related to the ground level were calculated from the change in the overall heat flow through the optimally insulated walls of the model home which resulted when the walls were placed deeper in the ground.

The results showed that insulation levels and the savings generated by them were sensitive to changes in fuel price with higher levels being frequently recommended at greater fuel costs. When the thermal characteristics of the soil were included in the analysis, the net savings generated by insulated wall designs declined $1400 to $6700 as the walls were placed deeper within the ground. Fuel consumption for these grounded designs was generally shown to increase over their above-ground, i.e. conventional, counterparts. The net savings generated by fiberglass insulation was greater than comparable savings from urethane in above-ground wall structures. Conventional and grounded designs using fiberglass usually had lower fuel consumption than comparable, walls insulated with urethane. Urethane designs, on the other hand, generated greater net savings in most grounded situations.

The study concludes that the cost minimizing wall design for residential buildings over a broad cross section of the nation is the above-ground structure framed with 2 x 4's 16 inches on center and insulated with R-13 fiberglass.

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Date January 20, 1978

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IN RESIDENTIAL WALL CONSTRUCTION: AN ECONOMIC ANALYSIS

by

CLIFFORD WALTER NIXON

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

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Chapter 1

INTRODUCTION

As finite energy reserves become depleted, increasingly higher cost sources of energy must be utilized. Such conditions may cause the price of fuels to rise with respect to the general price level. In this decade, the rise in energy costs has outstripped the general rate of inflation which indicates that fuels are becoming increasingly scarce in relation to other resources. The housing sector is one portion of the economy which has experienced this shift in relative prices. Consequently forces have appeared in this sector to shift resources away from energy consumption and towards energy conservation.

Rising energy prices provide incentives for homeowners to build more thermally efficient homes. Some new designs will, to be sure, embody energy concepts quite different from those currently used -- perhaps different enough to alter the appearance of the building and the utility derived from it. The homeowner's reaction to such structural changes in the building envelope are an important consideration determining the optimal allocation of resources. This can be easily demonstrated by considering two men's responses to energy conserving structures. The first man will not build a house whose walls are partially buried in the ground even if he understood that the design would yield the highest return on investment of all possible structures he could erect in his climate and terrain, but would build a house having 2 x 6 studding and R-19 insulation in the walls if it were more "conventional" in appearance. The second man rejects the more heavily insulated design which was acceptable to the first man on the grounds that the thicker walls require additional floor area.[1/] His choice might have 2 x 4 walls with R-13 insulation. These examples show that when preferences of the consumer are considered, increasing thermal insulation can be used as a substitute for fuel consumption.

STATEMENT OF THE PROBLEM

The problem is to define an economic model which will allocate energy related resources in the housing sector in an efficient manner. Such an undertaking requires that all savings resulting from and all costs incurred by each energy conserving modification to a residence, be clearly defined and representative of actual market conditions. The criterion by which decisions in this model will be made is cost minimization to the homeowner, ie. consumer, so costs involving his

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[1/] If a wall which adjoins the floor of a residence is made thicker inward, floor space available for occupancy is reduced but the external dimensions of the building are not changed. If the broadening of the wall is outward, additional floor space is required to underlay the expanded dimensions of the building. For additional information see footnote No. 8 on page 35.

preferences must also be accounted for, if the affected resources are to be optimally allocated.[2/]

OBJECTIVES

The objective of the economic model is to identify energy conserving modifications to a residential wall structure which will minimize costs to the homeowner. One goal of the study is the determination of optimal insulation levels within walls in a manner which is dependent on the local climate, specified homeowner tastes and preferences, alternative energy costs, and financial conditions. A second goal is the specification of the soil level height in "buried" wall designs. From these two results, net savings, which are defined as total savings minus total cost, will be calculated.

METHODOLOGY

To approach the problem, certain constraints are assigned:

1. The structural modifications are limited to current technology and built from commonly manufactured materials.

[2/] No potential savings from lowering the interior temperature of the dwelling during periods of heating and raising it during periods of cooling will be considered, as such conservation measures may alter homeowner costs related to comfort.

2. Consumer valuation of the changes which alter the physical appearance of the walls are assigned on a dollar basis so they can be appraised along with the materials and labor costs of the modifications. Through this approach, the expenses of living below ground and of thick walls which were faced by the two men in the example above, can be acknowledged as building costs. Penalty functions are used to convert consumer preferences into dollar costs. These functions are explicitly included in the standardized nomenclature used in this study. For more information see page 54.
3. All decisions are assumed to be made from the standpoint of the homeowner who will respond to the relative price of energy and of energy conserving modifications, as well as to his own personal preferences. Therefore, the cost functions used in the analysis are formulated as statements about homeowner choices as well as construction prices.

The economic model developed calculates the maximum present value dollar savings possible from energy conserving modifications in residential walls given assumptions about consumer preferences, fuel prices, financial conditions, and the local climate. Thermal engineering calculations are used to simulate the wall's performance. Provision is made to examine two concepts of wall design. They are the above ground wall and the partially buried wall which utilizes soil as a thermal barrier. In each case, the cost minimizing level of insulation is determined through marginal analysis. Optimal soil level heights are calculated through a cost minimizing procedure. The wall modeling and economic analysis are done by computer.

The results, which are listed in Chapter 4, are for the Bozeman, Montana area, but their application to other regions which have different climate and construction costs is described in the summary for the same chapter. By making the appropriate changes in the weather, fuel, and construction cost variables, results can be obtained for any region in the country.

DEFINITIONS

Wall thermal response and structure are described in the following special terms. The costs and savings functions used to define the characteristics of each design are also listed. All definitions are placed alphabetically, with the exception of the first five terms which are used in many of the subsequent definitions.

1. Living wall refers to that portion of the total solid wall area of a residence which is a part of the building envelope. Attic and unfinished basement walls are not of this type since they do not have the thermal characteristics or interior finish which is

suitable for human habitation.

2. Component 1 is the above ground frame portion of a living wall.

3. Component 2 is the above ground concrete portion of a living wall.

4. Component 3 is the below ground portion of a living wall. (Components 1, 2, and 3 form the basic building blocks of all wall designs. See Figure 1.1.)

5. Ground ratio (GR) is the percentage of the total living wall height which is component 1. Ground ratios are illustrated in Figure 4.5.

6. Berm wall refers to a living wall which is partly or wholly composed of components 2 and 3.

7. Component 1 wall costs = (insulation costs) + (thick wall costs) + (framing costs) + (interior and exterior wallboard costs).

8. Component 2 and 3 wall costs = (insulation costs) + (thick wall costs) + (concrete costs) + (framing or furring costs) + (interior wallboard costs) + (perimeter insulation costs).

9. Configuration refers to a particular living wall unit whose component areas are defined by the ground ratio.

10. Conventional wall refers to a living wall which is composed entirely of component 1.

11. Cooling hours are all hours when the outdoor drybulb temperature is 80°F or higher.