1984

Development of a building energy rating system for new single family residential buildings.

Podury. Satyanarayana
University of Windsor

Recommended Citation
Satyanarayana, Podury., "Development of a building energy rating system for new single family residential buildings." (1984). *Electronic Theses and Dissertations*. 1700.
https://scholar.uwindsor.ca/etd/1700

National Library
of Canada

Bibliothèque nationale
du Canada

Canadian Theses Service

Services des thèses canadiennes

Ottawa, Canada
K1A 0N4

CANADIAN THESES

THÈSES CANADIENNES

NOTICE

The quality of this microfiche is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Previously copyrighted materials (journal articles, published tests, etc.) are not filmed.

Reproduction in full or in part of this film is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30. Please read the authorization forms which accompany this thesis.

AVIS

La qualité de cette microfiche dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

Les documents qui font déjà l'objet d'un droit d'auteur (articles de revue, examens publiés, etc.) ne sont pas microfilmés.

La reproduction, même partielle, de ce microfilm est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30. Veuillez prendre connaissance des formules d'autorisation qui accompagnent cette thèse.

THIS DISSERTATION
HAS BEEN MICROFILMED
EXACTLY AS RECEIVED

LA THÈSE A ÉTÉ
MICROFILMÉE TELLE QUE
NOUS L'AVONS REÇUE

NL 339 (r. 86/01)

Canada

DEVELOPMENT OF A BUILDING ENERGY RATING SYSTEM FOR NEW SINGLE FAMILY RESIDENTIAL BUILDINGS

by

Podury Satyanarayana

A thesis
presented to the University of Windsor
in partial fulfillment of the
requirements for the degree of
Master of Applied Science
in
Department of Mechanical Engineering

Windsor , Ontario, 1984

ABSTRACT

With the growing importance of having energy conserving features in houses, the idea of having a label on the house that indicates the energy requirement of the house becomes attractive. A Building Energy Rating System is a method to rate the energy performance of a house on a scale which indicates its relative performance. An Energy Label can be thought of as a label that contains the energy rating information of the house. Analogous to the EPA mpg stickers on automobiles, Energy Labels will give an indication of the actual thermal performance of the house envelope. At present there is no energy rating system existing in Canada. Hence it was decided to develop a method of rating the energy performance of houses located in Canada.

This being a first such study in Canada to develop a building energy rating system, it was confined to the analysis of new single family, detached residences located in Windsor, Ontario, Canada. An optimum or a 'base case' house having all its components at the optimum level was first defined. The energy consumption of this house was then the optimum energy consumption for the type of houses considered. Any other house can then be rated relative to this house.

There were two main objectives of this study. The first objective was to develop a model to predict the annual space heating load of a house. The variable base degree approach was used to develop the model. The climatic conditions of the city of Windsor, Canada were taken as the basis for developing the model. The model was developed using the CIRA 1.c building energy simulation computer program.

The second objective was to develop an energy rating system to rate the energy performance of a house envelope relative to that of the base case house. The rating system was based on the model developed to predict the annual space heating load of a house. The rating system compares the annual heating load of a house with that of the base case house, and assigns a positive or negative rating to the house depending on whether the annual heating load of the house is higher or lower than that of the base case house. A sample Energy Label format has been suggested that would contain the energy rating of the house and other information such as the predicted energy consumption, the building load coefficient, and the south facing glazing area of the house that may be of interest to a potential buyer.

The model developed was validated against three houses located in Windsor. The first house was a single story house with a partially heated basement. The second house was a two story house with an unheated basement. The third house was also a two-story house but with a fully heated basement. The

model predicted the annual space heating load of the houses within 6% of the actual annual space heating loads.

A second model to predict the annual space heating load of a house was developed for the city of Ottawa. This model was similar to the model for the city of Windsor, and it was found that a single model could be used for both the locations. This suggested the possibility of using a single model for a group of closely located cities instead of a different model for each individual city. Further studies in this direction were recommended.

ACKNOWLEDGEMENTS

I would like to place on record my sincere gratitude to Prof. W. G. Colborne for his constant guidance and encouragement. I would also like to thank Dr. N. W. Wilson for his valuable suggestions.

The discussions I have had with my colleagues proved to be very helpful for this study, and I would like to thank them all for their assistance.

Words cannot express my profound gratitude to my parents for their blessings and encouragement without which I could not have accomplished so much.

I would also like to acknowledge the financial support provided by the Natural Science and Engineering Research Council, Canada, for this study.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I

INTRODUCTION

1.1 OVERVIEW

The idea of developing a Building Energy Rating System is not a new one. Buildings, like automobiles or refrigerators, have different energy consumption levels depending on their physical or structural characteristics. A poorly constructed house will consume more energy than a similar but well insulated house. A potential buyer of a house will not be able to appraise the true condition of the house by mere inspection. An apparently good house may have a high energy consumption while a second house, in an apparently bad condition, may be highly energy efficient. With the increasing awareness among the public of having energy-conserving features in their houses, the concept of having an energy label on the house that indicates the probable energy consumption of the house becomes attractive.

The idea of ratings already exists in the automobile industry. It is now mandatory for all cars to have a label (EPA mpg stickers) which indicates the fuel consumption of the vehicle under some standard conditions. Obviously, the label is not the sole criterion on which the buyer will base his decision. Other factors like the price of the vehicle, its appearance, the comforts offered, etc. also are considered before the vehicle is bought. A label is just one more yardstick to evaluate the vehicle. The importance of such a label increases greatly when two similar vehicles are to be compared. In such cases, the vehicle with a better rating on the label would be a better choice.

An energy label on buildings will perform a similar function as the EPA stickers on vehicles. In the case of buildings it is the energy consumption for space heating or cooling that varies from house to house. By having a label on the house that indicates its energy consumption, different houses can be compared.

Energy labelling of houses, if implemented, can provide valuable information to a potential buyer. Besides the energy consumption, the information that could be presented on an energy label is the south-facing glazing area of the house, an energy rating of the house compared to the optimum energy consuming house, etc. Using this information a buyer could compare different houses before taking a final decision. A house with a better energy rating compared to a second house may have other features that may not be attractive. Hence the energy label aids the buyer in evaluating the house, and may not be the only criterion on which to base a decision.

The advantages of the labelling system are not limited to indicating the energy consumption. Once confidence in the energy labels is developed and the labels are accepted by the public, houses without a label or with a bad rating may be difficult to sell.

Unlike labels for automobiles or electrical appliances, building energy labelling is a very complex procedure. The many factors that affect the energy consumption of the house like the building physical characteristics, outdoor weather conditions, the surrounding terrain conditions, etc. make it very difficult to develop a uniform energy label for all types of houses and for all locations. Thus in order to develop energy labels for houses some assumptions have to be made regarding the building parameters, the weather conditions, etc. In other words, some standard 'operating conditions' have to be defined to develop the labelling system. A little consideration will show that these standard operating conditions will be analogous to the operating conditions under which a vehicle will perform as indicated on the EPA mpg sticker.

As yet, there is no energy labelling system of any kind being used in Canada. As with any new concept that tries to introduce a change in the conventional trends, energy labelling of houses also may face some initial resistance from the public. Hence energy labelling of houses can be succesful only if it is accepted voluntarily by the public. This can be achieved if efforts are made, preferably by the government, to educate the public on the advantages of having energy labels on houses. The next step could then be to have a legal requirement to have an energy label on the house. The law could then require houses to meet a certain minimum energy consumption level. This would in effect be a performance standard for houses.

1.2 LITERATURE SURVEY

Over the last few years, several utilities in the United States have developed and adopted voluntary energy labelling schemes for new houses. The states of Minnesota and Florida already have a successful energy labelling system (Ref 1). The state of Massachusetts also has adopted a Home Energy Rating System (HERS) that has been added to an existing RCS(Residential Conservation Service) rating of homes (Ref 2). The state of California is trying to implement such an energy labelling system. The following paragraphs describe the Minnesota Energy Conservation Rating System and the Massachusetts HERS systems being used.

The Minnesota Energy Rating system was developed at the Lawrence Berkeley Laboratory, Energy and Environment Division (Ref 3) for the state of Minnesota. This system is based on the energy conserving potential of the different components of the building envelope. The components that were considered were walls, ceiling, windows, infiltration, basement walls, automatic thermostat set-back and appliances & equipment present in the house. The rating is a scorecard type of system. The house considered for rating was a typical house located in Minnesota with average proportions and dimensions. Walls and ceiling were rated on their R-values. The energy loss due to a component was converted into points. The optimum R-values of walls and ceiling were assigned 0 points. Then, depending on the energy saving potential of the component, positive or negative points were assigned. Positive points indicated that, on the average, the component had a lesser energy saving potential than that at the optimum level, and vice versa. As average house proportions were assumed, changes in wall or ceiling areas were not considered. The glazing area was varied from that at the base case level, and points were assigned for different glazing areas.

In order to rate the infiltration component of energy loss, infiltration was classified as loose, standard, tight and very tight corresponding to certain ach values. Appliances and equipment were rated based on the manufacturer's efficiency rating. For equipment like wood stoves, a method was devised to arrive at a point rating based upon an estimate of the number of cords of wood that will be consumed in one year (Ref 3).

As the energy consumption for space heating depends on the type of heating equipment being used, different rating systems were developed for houses with gas or oil furnaces, heat pumps and electric resistance heating. In each case some standard efficiency for the heating system was assumed.

There are certain disadvantages to the Minnesota Energy Rating system:

1. As the energy consumption of the house depends on the type of heating system being used, different rating systems have to be used for rating a house even though the houses may be similar in all other respects.
2. The rating is very location-specific. As the energy consumption of the house also depends on the outdoor weather conditions, the points assigned for the measures will be different for different locations. The rating system, hence cannot be used for any other location.
3. The assumption that all houses will conform to the average house proportions assumed may not be correct. The size of a house can vary greatly even in a given location. There can be a significant change in the energy consumption of a house which has a larger ceiling or wall area than that assumed in the rating system. No allowance has been made to take into account the variation in the area of the building envelope components. In such cases, the energy consumption predicted by the rating system will not be the actual energy consumption of the house, and so the rating of the house also will not be the true rating.

4. Finally, it is debatable whether to consider heating or cooling equipment as an integral part of the house. Equipment like air-conditioners can be easily installed or removed and need not be a permanent component of the house (Ref 4).

Tarini (Ref 2) and others developed a Home Energy Rating System (HERS) for the state of Massachusetts. This system uses an existing RCS audit program to collect rating information and provide a rating. The rating has two parts: the first part provides a score of relative efficiency for the house, and the second part provides the predicted heating cost. The rating system was developed using the CIRA building energy simulation computer program using the weather conditions of the city of Boston. Several building envelope components like ceiling, wall and floor insulation, windows, air infiltration, and also the solar gains and the heating system were considered for developing the rating system.

A base case house having no insulation, and with an extremely leaky structure was first defined. The seasonal heating load was determined using the CIRA program. Points were then assigned to how well each change, in insulation level, for example, reduced the heat load as compared to the base case house. The heating system present in the house was also considered as a part of the rating system, and points were assigned for different types of heating systems depending on their efficiencies. Standard assumptions were made for internal gains.

The rating system was presented in the form of tables called Rating Forms. The ratio of wall area to ceiling area was chosen as the basis for each rating form. Eight different rating forms were developed for eight wall-to-ceiling ratios. The rating points of each component are summed up and the overall rating is determined from this value.

Incidentally, a similar approach was initially adopted in the present study. A base case house having all its components at their optimum levels was first defined. The internal gains were assumed to be constant. The net annual heat loss from the house was determined by using the CIRA 1.a building energy simulation computer program. This value depends on the conduction, infiltration & radiation losses, and the solar gains into the house. The relative contribution of each component of the house envelope was then determined by eliminating one component at a time, for example walls, and finding the net annual heat loss once again using the CIRA program. The difference between these two heat loss values gave the contribution of the wall component toward the total heat loss from the house. The relative heat loss of each component was converted to points, each point representing a certain heat loss value in MBtu. A point rating scale was then developed for each component for different levels of the component, for example different R-values of walls. This method was later discarded for the following reasons, which to a certain extent, apply to the Massachusetts HERS system also.

1. CIRA 1.a building energy simulation computer program is one of the earlier programs developed by the Lawrence Berkeley Laboratory, California. This program was found to have certain faults and inaccuracies and was subsequently revised. The new and more accurate version of the program, CIRA 1.c, is basically a sophisticated variable base degree day program that determines the annual heating degree days based on the balance point temperature of the house. The program does not calculate conduction losses, infiltration losses ,etc. through each building component. The earlier assumption that these heat losses were calculated by the program was incorrect. The Sky-radiation loss and the solar gains can,however, be obtained from CIRA.
2. The effect of any component on the heating load of the house may not be independent of the effects of the other components. For example the effect on the heating load of increasing the wall insulation in a poorly constructed house will be greater compared to that in a house which has high insulation levels and a tight structure. It may be inaccurate to assume

that increasing the wall insulation by a certain amount will bring about the same change in the heating load in all houses.

3. The heating energy consumption of a house depends not only on the building envelope characteristics, but also on the outdoor weather conditions which are location-specific. The points assigned for energy savings for each component will therefore differ with location.
4. Once again, it is debatable whether to consider the heating system as an integral part of the house.

Blancett (Ref 5) developed a method of rating the thermal performance of a house envelope relative to an energy efficient house taken as a standard. In this approach, the U-value of the different components of the house envelope were first converted to points and then summed up to get an overall U-point for the house. The areas of the individual components were normalized by dividing by the floor area of the house. The basic ASHRAE Degree-Day equation was then used to determine the annual heating load of the house. This method considered only the heating season. The degree day values to the base 65°F were used to calculate the heating load. The main disadvantage of this method is that the balance-point temperatures of new houses are considerably below 65°F. The traditional use of 65°F-based degree-days is founded on correlations between energy and degree-days made in the 1930's. New houses have considerably higher insulation levels, have lesser infiltration, increased solar and internal gains, etc., resulting in balance-point temperatures much lower than 65 F. Thus the energy consumption determined by using the 65 F base degree days will be much higher than the actual energy consumption, typically 25 to 30% (Ref 6). While such conservative over-prediction may be acceptable for design purposes for individual residences, a more accurate method is required to determine the energy consumption of houses.

1.3 OBJECTIVES

This study is the first step in the development of an energy rating system for houses located in Canada. The scope of this study is confined to the demonstration of this system to a typical new single family house located in Windsor, Ontario, Canada.

Based on an analysis of the existing energy rating systems, a different approach was judged to offer some advantages. The objectives of this study are as follows:

1. To suggest a procedure that will lead to the use of Energy Labels for new, single family residences.
2. To develop an easy-to-use, yet accurate, building energy rating system that compares the thermal performance of building envelopes in a given location.

3. To develop a model for predicting the annual space heating load of new, single family residences.

The energy rating system will compare the annual space heating loads of different houses under the assumption of standard internal gains and indoor heating temperature set-point. The energy rating and other information such as the probable energy equivalent of the fuel used for space heating, etc. will be presented on an Energy Label in a manner that can be easily understood by a potential buyer.

In order to compare the annual space heating load of houses under the above assumptions, it is necessary to develop a model that determines the annual space heating load of a house under these assumptions. A model will therefore be developed using the CIRA 1.C building energy simulation computer program.

Chapter II

THE BASE CASE HOUSE

This chapter describes the principles underlying the selection and definition of the Base Case House, and its modelling in the CIRA computer program. The chapter is divided into four sections. The first section gives a brief description of the CIRA energy simulation program, and the reasons for selecting this program.

The second section describes the Energy Labels and their advantages. A sample format for an Energy Label is presented which can be easily understood and used. The third section defines the optimum or the Base Case house for Windsor. All assumptions made in the process are clearly delineated. The last section presents the modelling of the Base Case house in the CIRA simulation program.

2.1 CIRA ENERGY SIMULATION PROGRAM

The CIRA 1.c energy simulation computer program is a micro-computer based energy simulation program developed at the Lawrence Berkeley Laboratory, University of California. CIRA, or Computerized Instrumented Residential Audit, is a user-friendly energy simulation program which determines the annual heating and cooling energy consumption of residential buildings. Unlike other energy simulation programs, such as DOE 2.1, CIRA is a relatively simple program capable of handling different types of houses, with or without basements, passive solar measures, different heating or cooling appliances, etc. The input of a house in CIRA can be done by simply answering the questions posed by the program. For questions that cannot be answered without a detailed knowledge of the house, e.g. information regarding the leakage characteristics of the walls and ceiling, etc., the DEFAULT facility in-built in the program can be used. On the other hand, detailed information of the house is required to use energy simulation programs like DOE 2.1.

CIRA is basically a sophisticated degree day program that computes the energy consumption of the house. Variable base degree days are calculated for each month of the year for the house (Ref 7). An effective outdoor temperature is first determined using the actual outdoor temperature, solar gains, free heat and the building load coefficient of the house. The effective outdoor temperature is defined as 'that outdoor dry-bulb temperature that would produce the same heat transfer through the envelope by conduction and convection only, under steady-state conditions, as the superposition of conductive, convective and radiative heat transfer (short and long-wave) and internal "free heat" actually occuring' (Ref 7). The relation between the effective outdoor temperature T_e and the conventional base temperature T_b is given by the equation:

$$T_e - T_o = T_i - T_b$$

where T_o is the actual outdoor temperature.

This effective outdoor temperature is then used to calculate, using an empirical relation, the variable base degree days of the house. The higher the effective outdoor temperature of the house, the smaller is the variable base degree days of the house, and vice versa. The program performs only monthly energy calculations and hence the time taken for one complete energy calculation is very small (approx. 2 minutes). This offers a tremendous opportunity to make a detailed study of the different components of a building like the wall and ceiling R-values and areas, different glazings, infiltration etc. CIRA has also stored weather data for a number of cities both in Canada and the United States, with the provision of adding other cities to the list. These weather files can be used to study a house under different weather conditions.

Considering the numerous advantages offered by the CIRA energy simulation program, it was logical to use this program for developing the energy rating system.

2.2 ENERGY LABELS

An energy label fixed to a house would indicate the probable energy consumption of the house. An energy label should be easy to understand and should contain a meaningful appraisal of the house. Though the information presented on the energy label could be updated after a certain time, the data should be as accurate as possible. This information should be selected carefully so as to give a true and comprehensive picture of the house condition. Even though the primary purpose of the energy rating system is to arrive at a rating value for the house envelope, certain other information can be obtained indirectly from the system. For example, the annual energy consumption of the house can be calculated once the building load coefficient, the variable base degree days, and the efficiency of the heating system are known. Of these three factors, the first two can be obtained from the rating system. The heating system efficiency could either be estimated or obtained from the nameplate on the system. An Energy Label can be utilized to indicate not only the energy rating of the house envelope, but also such information that would be relevant to a potential buyer. A suggested format of an Energy Label is presented in Table 2.1. The information presented on the label was chosen so as to be readily available from the energy rating system to be developed in this study.

The following paragraphs discuss the various parameters presented on the energy label.

1. The type of heating system present in the house should be indicated here. Any system that does not come under the three heating systems shown can be specified separately. The steady-state efficiency is

the bonnet efficiency of the heating system. This value is used to determine the energy efficiency of the house.

2. The annual energy equivalent of the fuel used for heating the house is based on an assumed seasonal efficiency for the heating system. For gas furnaces, a seasonal efficiency of 70% was assumed. An efficiency of 85% was assumed for high efficiency condensing furnace.
3. The energy efficiency of the house is defined as the annual heating energy consumption per unit floor area. Houses with different sizes will have different energy consumptions, e.g., a house with twice the floor area of the optimum house may consume twice the energy annually. By normalizing the energy consumption of the house by its floor area, all houses could be brought to a common denominator to perform a meaningful comparison. This eliminates the possibility of penalizing a house because of its size (Ref 5).
4. The optimum energy efficiency is the energy efficiency of the optimum house for the given location. The optimum house for Windsor has been defined in Section 2.3 of this chapter. Comparing the energy efficiency of the house with the optimum energy efficiency gives the potential buyer a good indication of the condition of the house.

TABLE 2.1

A Sample Energy Label Format

Location of the House :

Heating system: Gas or oil furnace ( )
Electric resistance ( )
Heat pump ( )
Other (specify) ....

System steady-state efficiency : ....

Annual energy equivalent of

fuel used for heating : .... KWH

Energy efficiency of the house : .... KWH/sq.m

Optimum Energy efficiency : .... KWH/sq.m

Building Load Coefficient : .... W/°C

Energy Rating of the house : .... %

Living floor area : .... sq.m

South-facing window area : .... sq.m

<u>CAVEAT</u>:

The energy consumption of the house may vary from that indicated on the Energy Label if the building operating conditions are different from the standard building operating conditions

5. The energy rating of the house is the difference between the annual heating load per unit floor area of the house and the base case house, expressed as a percentage of the annual heating load per unit floor area of the base case house. A positive energy rating indicates that the house has a better building envelope compared to the base case house, and vice versa.
6. South facing glazing area of the house is a feature that may be of interest to a potential buyer. This is a property of the design of the house envelope.
7. Building load coefficient (BLC) is the overall UA value of the house. This is a measure of the quality of the house envelope. High BLC values mean low insulation levels or higher infiltration into the house, or a house with large component areas. Low BLC value indicates either a tight structure with high insulation levels, or a small house. In general, the higher the BLC of the house, the higher is the energy consumption of the house for space heating. Though scientific in nature, its use may become common once the public gets familiar with this term.

2.3 DESCRIPTION OF THE BASE CASE HOUSE

The first step in developing a rating system is to identify the components of the building envelope that should be further considered. As the major objective of this study was to analyze the building envelope, only the physical components of the envelope were considered for developing the rating system. Certainly other factors such as internal gains due to occupants, thermostat set-back, appliances and equipment, etc., have a significant effect on the energy consumption of the house. Living habits vary greatly, and apparently similar houses may still have very different energy use patterns. Policy decisions would perhaps be required to decide if the above factors should be included in the rating system since it could be argued that these factors do not form a part of the house. Also the complexity of including these variables makes it virtually impossible to develop an energy rating system that would be simple and yet accurately predict the energy consumption.

A building envelope consists of the following components:

1. The exterior walls of the structure.
2. The ceiling or roof of the structure.
3. The glazing in the windows and doors, and the doors present in the exterior walls of the structure.
4. Infiltration into the structure due to cracks in the walls and around windows and doors.
5. Basement walls and floor.

Of the above five components, all but infiltration are the physical components of the structure. Infiltration is directly dependent on these physical components and so can be classified as a physical component of the house. The heat loss due to infiltration may be as high as 25-30% of the total building heat loss, and therefore it is important to include infiltration for the purpose of developing the rating system.

In most Canadian locations the energy consumed for heating is much higher than the energy consumed for cooling the house. Hence it was decided to restrict the analysis to the heating season only.

2.4 MODELLING OF THE HOUSE IN CIRA

Once the decision regarding the components was made, the next step was to define an energy efficient construction standard for these different components. Two cases were considered for the study:

1. A single family house with an unheated basement
2. A single family house with a heated basement.

It was found in a statistical survey (Ref 8) that over 80% of the homes in all regions except British Columbia have basements. The fraction for British Columbia is about 51%. This study therefore analyzed houses having basements. The fraction of the basements that are heated is not known, therefore both heated and unheated basements were considered in this study. The optimum house, henceforth called the Base Case House, has all its components at their optimum or recommended levels. The energy consumption for this Base Case house will be at the optimum level. Any other house that is different from this house can then be compared with this house.

A sketch of the plan and elevation of the base case house is shown in figure 2.1. The floor area of the base case house is 1000 sq.ft. This is the total or gross floor area of the house excluding the thickness of the exterior walls. The exterior wall area also was assumed to be 1000 sq.ft.

In order to define the structural details of the house, the optimum R-values of walls and ceiling had to be determined. The procedure for calculating the optimum R-values is shown in appendix B. An economic life period of 30 years was assumed (see Ch.20, Ref 11). The cost of electricity and gas for the year 1983 obtained from the Windsor Utilities were $13.18 per MBtu and $5.75 per MBtu respectively. The optimum R-value for the wall was determined to be 21 h.sq.ft.F/Btu, and for the ceiling as 26 h.sq.ft.F/Btu. The equivalent SI values are presented in appendix A.

There is no simple procedure for determining the optimum U-values for window glazings and doors. Hence values recommended in Ref 9 were used. The U-value recommended for window glazings was 0.588 Btu/h.sq.ft.F. This U-value can be

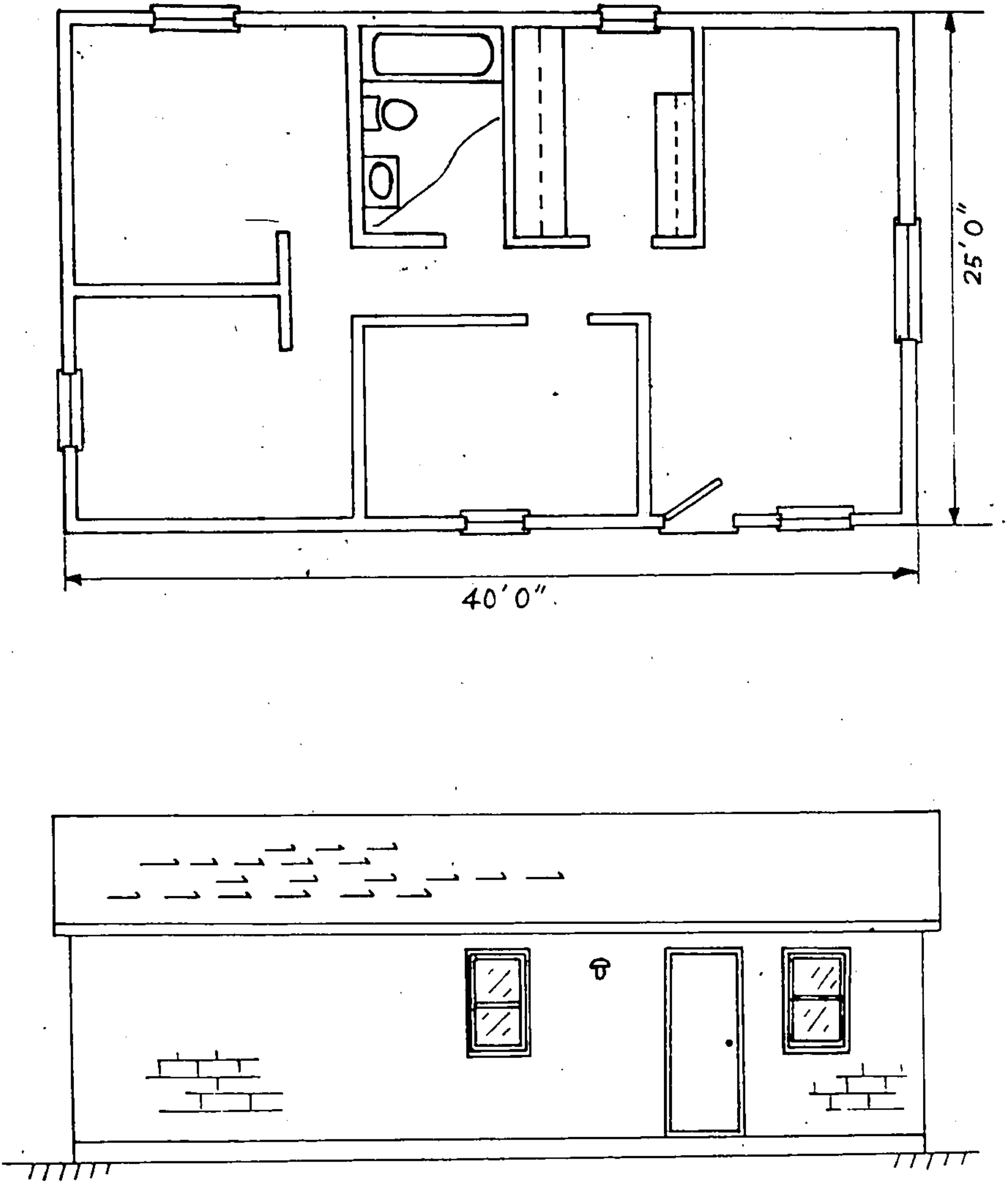

FIG 2.1 Plan and Elevation of the Base Case House

achieved by having a double-pane glass with 0.25 inch air space. A total glazing area of 10% of the floor area was assumed. For the base case house this corresponds to a total glazing area of 100 sq.ft. The windows were distributed uniformly on all four elevations to simulate random orientation. The recommended R-value for doors was 4.0 h.sq.ft.F/Btu, or a U-value of 0.25 Btu/h.sq.ft.F. A door of 21 sq.ft. was assumed to be present in the south facing wall of the house.

Infiltration was described in terms of a leakage number LN for the house. A LN value is an indication of the leakage characteristic of the house structure. A LN value of 0.0 indicates that the house has a very tight structure. A LN value of 4.0 indicates a very loose structure. The ENCORE CANADA simulation program specifies a value between 2.0 and 2.5 (Ref 10) for an average house structure. In order to determine the leakage area of the different components of the house, default values were used in the CIRA program. The infiltration determined by the program corresponded to a LN value of 2.2 under the design weather conditions of Windsor obtained from ASHRAE 1981 Fundamentals (Ref 11). Thus this LN value of 2.2 was assumed to be the average value for Windsor.

The two cases considered for developing the rating system, viz., a house with an unheated basement, and a house with a heated basement were input seperately in the program and analyzed. For unheated basements, according to ASHRAE (Ref 11), in general, "heating plant present in the basement sufficiently warms the air near the basement ceiling to make an allowance unnecessary for floor heat loss from rooms located over the basement". The basement, therefore, was modelled to reduce the heat loss from the basement ceiling to a minimum. The technique to do this in the program is to install a very high insulation between the floor joists. This value was the maximum allowed in the program of 80 h.sq.ft.F/Btu. The floor area was reduced to the minimum of 20 sq.ft. allowed in the program. Also, the R-values of the basement walls and floor were input the maximum allowed.

To model a heated basement, it was first assumed that the above grade height of the basement wall was 1 ft. The R-value and the leakage characteristics of the basement walls were determined by default. Once the above-grade R-value and the soil-conductivity are known, CIRA calculates the equivalent below-grade R-value. The soil conductivity was assumed to be 9.6 Btu.in/h.sqft.F. This value is specified in Chapter 25 of the ASHRAE 1981 Fundamentals (Ref 11).

To complete the input of the house in CIRA, data had to be entered for the heating equipment and other appliances existing in the house. This data was then used by the program to compute the internal gains in the house. It was assumed that the heating system was a gas furnace with a seasonal efficiency of 70%. As the analysis was restricted to the heating season only, no cooling equipment was input. The thermostat set-point was 70°F. There was no night set-back. It was also assumed that there were four people in the house. Using these values, CIRA determined the internal gains of the house as approx. 2500 Btu/h, or 60,000 Btu/day. Table 2.2 summarizes the structural details of the house. See appendix D for the detailed house input in CIRA.

TABLE 2.2

Input Details of the Base Case House

Structural Details :

Type : New single family, wood frame ranch with a full basement.
Floor area : 1000 sq.ft.
Wall area : 1000 sq.ft.
Exterior wall : R-21 insulation (total)
Ceiling : R-26 insulation (total)
Windows : Double glazed
Window area : 100 sq.ft., distributed equally on all four elevations
Doors : One solid core flush door with a metal storm.

HVAC System :

Controls : 70°F heating set-point, no night set-back.
Heating equip. : Gas-fired forced-air furnace
Cooling equip. : None
Occupants : Four people.

Chapter III

DEVELOPMENT OF THE ENERGY RATING SYSTEM

The objective of this chapter is to describe the procedure adopted to develop the rating system, and the rating system developed. The chapter is presented in two sections. The first section describes the basic equations underlying the system. The second section describes the rating system developed using these basic equations. This section is subdivided into three subsections.

3.1 THE DEGREE DAY EQUATION

An energy rating system that is capable of being general in nature should be based on a characteristic property of the building envelope. The rating system should not be affected by the heating system being used, the life style of the occupants or by other such 'extrinsic' properties of the house. The ASHRAE Degree Day equation is such an equation. It determines the annual heating load of a house using only the annual heating degree days of the location and the building load coefficient of the house. This equation can be written as:

$$HL = (\Sigma UA) \times DD \times C_D \times 24 \qquad \ldots(3.1)$$

where,

HL = annual heating load in Btu

ΣUA = Building load coefficient, Btu/h.F

DD = annual heating degree days, F-days

The actual ASHRAE degree day equation uses the degree days to the base 65°F. The factor C_D is a function of the degree days of the location only. This is an empirical factor that takes into account the lower balance point temperatures of new houses. The graph in Fig.1, Chapter 28 of the ASHRAE Handbook of Fundamentals (Ref 11) shows the relation between the correction factor C_D and the degree days (base 65°F) for any location. The term (DD X C_D) can be understood to represent a modified annual heating degree day value of the house.

A possible approach to determine the variable base degree days of a house in any location is to express the degree days of the location for different base temperatures. Recent work has been done (Ref 12) in the United States to determine the annual heating degree days of a location as a power function of the base temperatures. Then, knowing the base or balance-point temperature of the house, the corresponding variable base degree days can be calculated. This is a better approach than the ASHRAE modified degree day method which uses a single value for the C_D factor for all houses in a given location.

Two drawbacks of this method are immediately apparent. Determining the balance-point temperature of any house is not easy. This temperature depends on many complex factors like internal gains from the occupants, appliances, etc., which cannot be quantified easily. Though some approximate methods have been suggested for commercial and industrial buildings (Ref 13), their accuracy for residential buildings is not known.

The second drawback, as applicable to this study, is that no work has been done to determine the degree days for various base temperatures for locations in Canada. The only useful data available for Canadian locations is the annual heating degree days for base 65°F. Thus such an approach, though attractive, was not done for this study.

A second possible approach, as adopted in this study, is to determine the variable base degree days of a house using an energy simulation computer program. For reasons mentioned in Section 2.1 of the previous chapter, CIRA was chosen to develop such an approach. The effect of the various components on the annual variable base degree days of the house can be investigated by analyzing a prototype house under different conditions.

The variable base degree days of a house, in general, depends on the following factors:

1. The BLC of the house, i.e., on the transmission and infiltration losses from the house.
2. The glazing area, i.e., the solar gains into the house.

3. Internal gains.

The effect of thermal mass on the annual energy consumption of ordinary houses is not significant (Ref 14 & 19). Hence for this study the effect of thermal mass of the house has been neglected. The internal gains were considered to be a constant as the analysis was restricted to the building envelope only. The DD of the house will then depend only on the first two factors. The effect of these two factors on the DD of the house was studied by varying the BLC and the glazing area of the house.

The modified degree day equation for the base case house can be written as:

$$HL = \Sigma UA \times DD \times 24 \qquad \ldots(3.2)$$

where,

HL = annual heating load of the base case house

ΣUA = BLC of the base case house

DD = variable base degree days for the base case house as computed by CIRA

Now, for any other similar house, the above equation can be written as :

$$HL' = (\Sigma UA + \Delta UA) \times 24 \times (DD + \Delta DD) \qquad \ldots(3.3)$$

In this equation the ΔUA term indicates the difference in the building load coefficient of the second house from that of the base case house. This change in UA can be caused by either a change in the U-value or a change in the area of a component of the building envelope. Thus the ΔUA term indicates the difference in the physical structure of any house compared to the base case house. Note that ΔUA can be either positive or negative. A negative value indicates that the house is either smaller in size or it has more insulation and a tighter construction. The ΔDD is the corresponding change in the variable base degree days of the house due to a change in the BLC of the house. The ΔDD is determined with the DD of the base case as the reference value. Thus if the ΔDD of a house can be expressed as a function of the ΔUA of the house, the heating load can then be calculated from eq. 3.3. Observe that this approach obviates the need of calculating the balance-point temperature of the house. The ΔUA of the house can be easily determined from the structural details of the house. Equation 3.3, in essence, represents the second approach mentioned above.

The next few sections describe the analysis of the base case house using the CIRA program and the rating system developed using this analysis.

3.2 THE ENERGY RATING SYSTEM

The Energy Rating System determines the annual heating load of the house, and using this data determines the energy rating of the house. The user of the rating system simply fills in the required data, and with simple calculations arrives at the energy consumption and the energy rating of the house.

An energy rating should be both accurate and simple to use. Once the base case house was defined, it was input in the CIRA program for analysis. A summary of the CIRA output for this house is shown in Table 3.1 (see appendix E for the detailed output). The table shows the output for the house with an unheated basement. The annual heating degree days of the house was 3906 F-days, and the building load coefficient was calculated as 238 Btu/h.F. The corresponding annual heating load was 22.3 MBtu.

As the analysis for the heated basement case is similar to the unheated basement case, the development of the energy rating system for the unheated basement case only will be presented in this section. The energy rating system was based on the above data of the base case house as the reference. The rating system was subdivided into three sections as described below.

3.2.1 SECTION I

In order to determine the annual heating load and the energy rating of any house, the house details such as the total insulation R-values of walls and ceiling, area of walls, ceiling and windows, etc. are required. It is assumed that this data is available to the user of the rating system. Therefore no procedure will be provided to obtain this data.

TABLE 3.1

CIRA Simulation Results of the Base Case House

Unheated Basement:	
Building Load Coefficient	238 Btu/h.F
Annual heating variable base degree days	3906 F-days
Annual daytime sensible heating load	8.5 MBtu
Annual nighttime sensible heating load	13.8 MBtu
Annual gas use for space heating	421 Therms
Space conditioning energy use (heating)	42.1 MBtu
Mean infiltration (heating season only)	.61 ac/h
Free heat	2507.36 Btu/h

TABLE 3.2

SECTION I

Walls, Floor, Windows and Door areas :

1. Net living floor area of the house (excluding basement) (A) .... sq.ft.
2. Ceiling area (B) .... sq.ft.
3. Gross exterior wall area (C) .... sq.ft.
4. Window area on the South facing side (D) .... sq.ft.
5. Window area on the East facing side (E) .... sq.ft.
6. Window area on the West facing side (F) .... sq.ft.
7. Window area on the North facing side (G) .... sq.ft.
8. Door area (H) .... sq.ft.
9. Sum of items D to H (I) .... sq.ft.
10. Net exterior wall area (J) .... sq.ft.

Table 3.2 shows the first section of the rating system. Data for the wall, floor, window and door areas, have to be entered. The floor area does not include the basement floor area. Item C is the gross wall area of the house. Items D to F are the windows and door areas on all sides of the house. Subtracting the total of these areas from the gross wall area gives the net exterior wall area of the house. The data entered in this section will be used in sections II and III described next.

3.2.2 SECTION II

This section compares the building envelope of any house with that of the base case house. The building load coefficient of the house is determined with respect to the base case house. This is then the overall ΔUA value of the house. In order to obtain this value, the UA values of the individual components of the house were compared with the corresponding components of the base case house. The UA values of the components of the base case house were taken as the reference values. Therefore summing the individual ΔUA of the components of the house gives the overall ΔUA of the house with respect to BLC of the base case house. This will become clearer when the individual components are described below. The section itself is presented in the form of graphs for the various components.

1. **WALLS** : The optimum R-value of the base case wall was determined as 21 h.sq.ft.F/Btu (see appendix B). The net wall area was assumed to be equal to 1000 sq.ft., equal to the floor area of the house. The UA due to walls was calculated as 47.6 Btu/h.F for the base case house. For any other house with a different wall area or R-value, the value of UA-wall will be different from that of the base case house. Taking the UA-wall of the base case house as the reference value, the ΔUA-wall of the house can be computed. This is shown in Fig. 3.1. The abscissa is the R-value of the walls, and the ordinate is the ΔUA of the walls. The figure shows a family of curves, each for a different net exterior wall area. The curve for 1000 sq.ft. wall area intersects the abscissa at R-21 and corresponds to a ΔUA equal to 0. The curves were generated by determining the ΔUA's for various combinations of R-values and wall areas. By increasing the R-value of the wall, for a given wall area, the UA of the wall decreases. Similarly, by increasing the wall area at a particular R-value increases the UA of the wall.

In order to determine the ΔUA-wall for any house, locate the R-value of the wall on the abscissa. Knowing the net wall area of the house from section I, draw a vertical line to intersect the corresponding area curve. Read off the ΔUA-wall across on the ordinate.

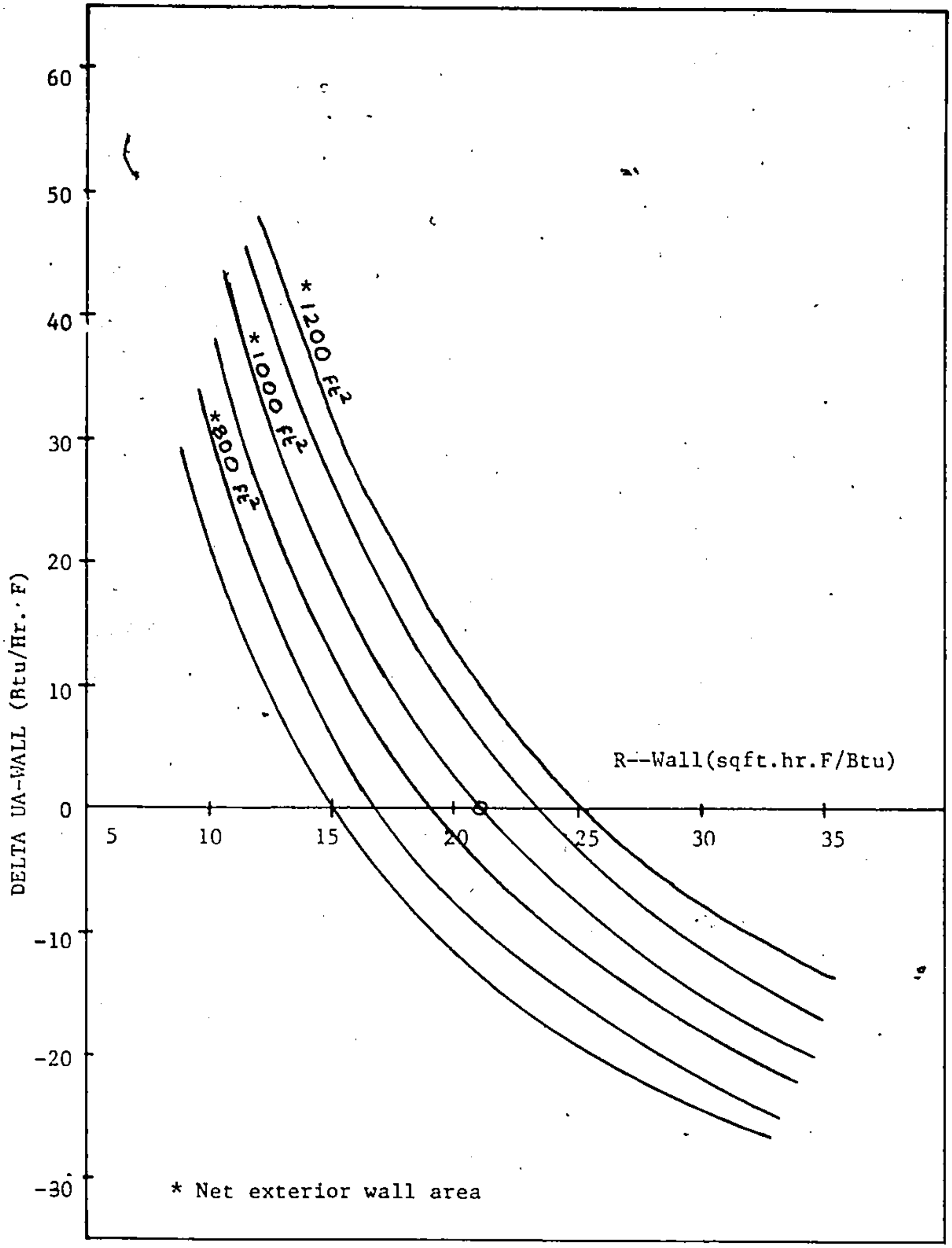

FIG. 3.1 Graph to determine Delta UA-wall for different wall areas and R-values

2. CEILING : The optimum R-value of the base case ceiling was determined as R-26, and the area was 1000 sq.ft. The UA-ceiling was then calculated to be 38.5 Btu/h.F. Fig. 3.2 shows the curves for determining the ΔUA-ceiling for any other house. The abscissa represents the R-ceiling, and the ordinate represents the ΔUA-ceiling. The datum point on the ordinate is the UA-ceiling of the base case house. The curve for 1000 sq.ft. intersects the abscissa at R-26.

In order to determine the ΔUA-ceiling of the house, locate the R-value of the ceiling on the abscissa. Draw a vertical line to intersect the corresponding area curve. Read off the ΔUA-ceiling across on the ordinate.

3. DOORS : Taking the U-door equal to 0.25 and the door area of 21 sq.ft. of the base case house, the datum point on the ordinate in Fig. 3.3 was calculated as UA=5.25 Btu/h.F. It was assumed that there was one door of area 21 sq.ft. in the base case house. The abscissa represents the U-door. A U-door of 0.25 can be achieved by having a solid core flush door with a metal storm door. The ΔUA-door can be determined in a similar way as for walls and ceiling.

4. WINDOWS : The total glazing area in the base case house was assumed to be equal to 10% of the floor area, or 100 sq.ft. The window U-value was 0.588 Btu/h.sq.ft.F. Fig. 3.4 shows the graph to determine the ΔUA-window of any house. The abscissa represents the U-window, and the ordinate represents the ΔUA-window. A U-window of 0.588 can be

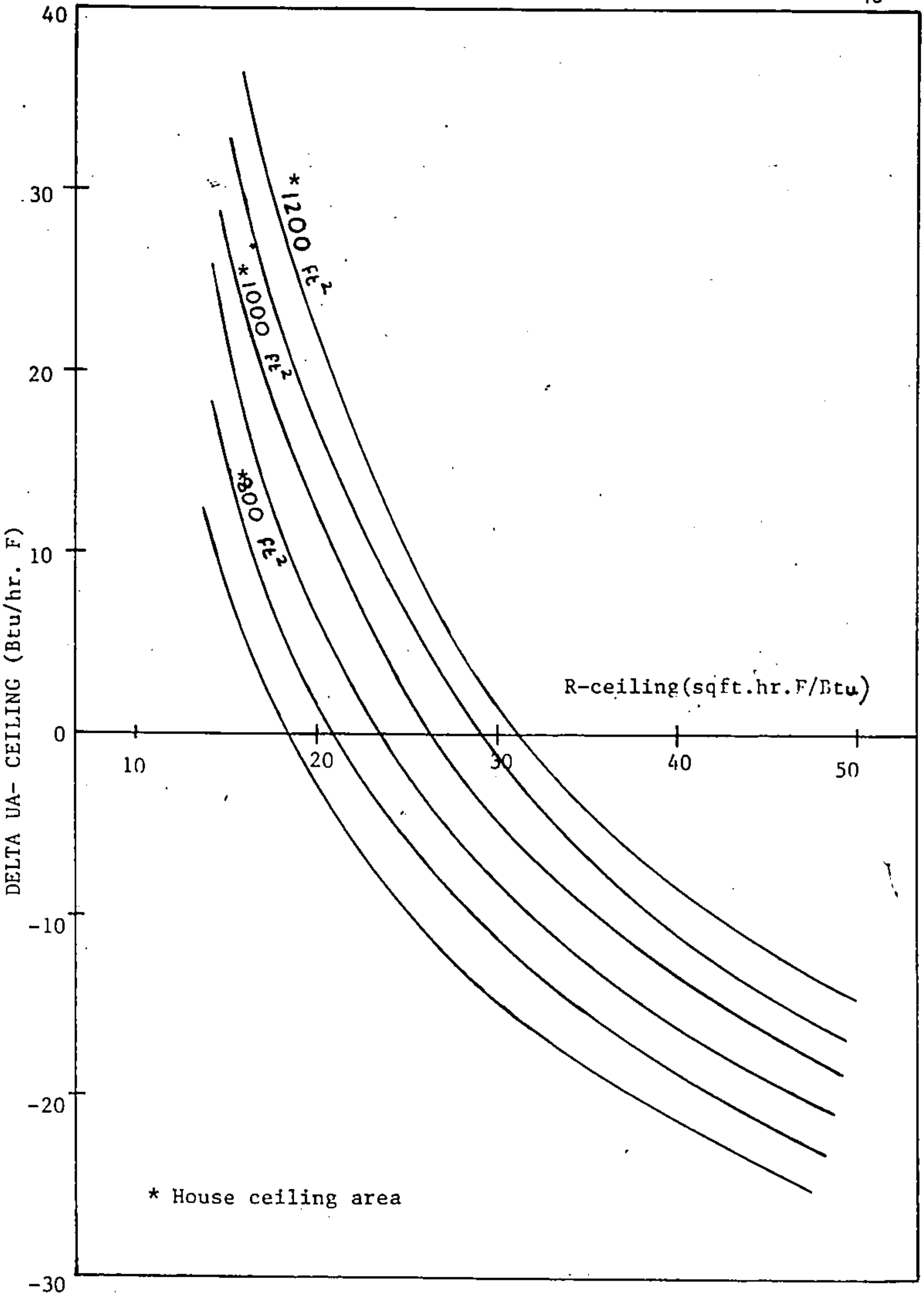

FIG. 3.2 Graph to determine Delta UA-ceiling for different ceiling areas and R-values

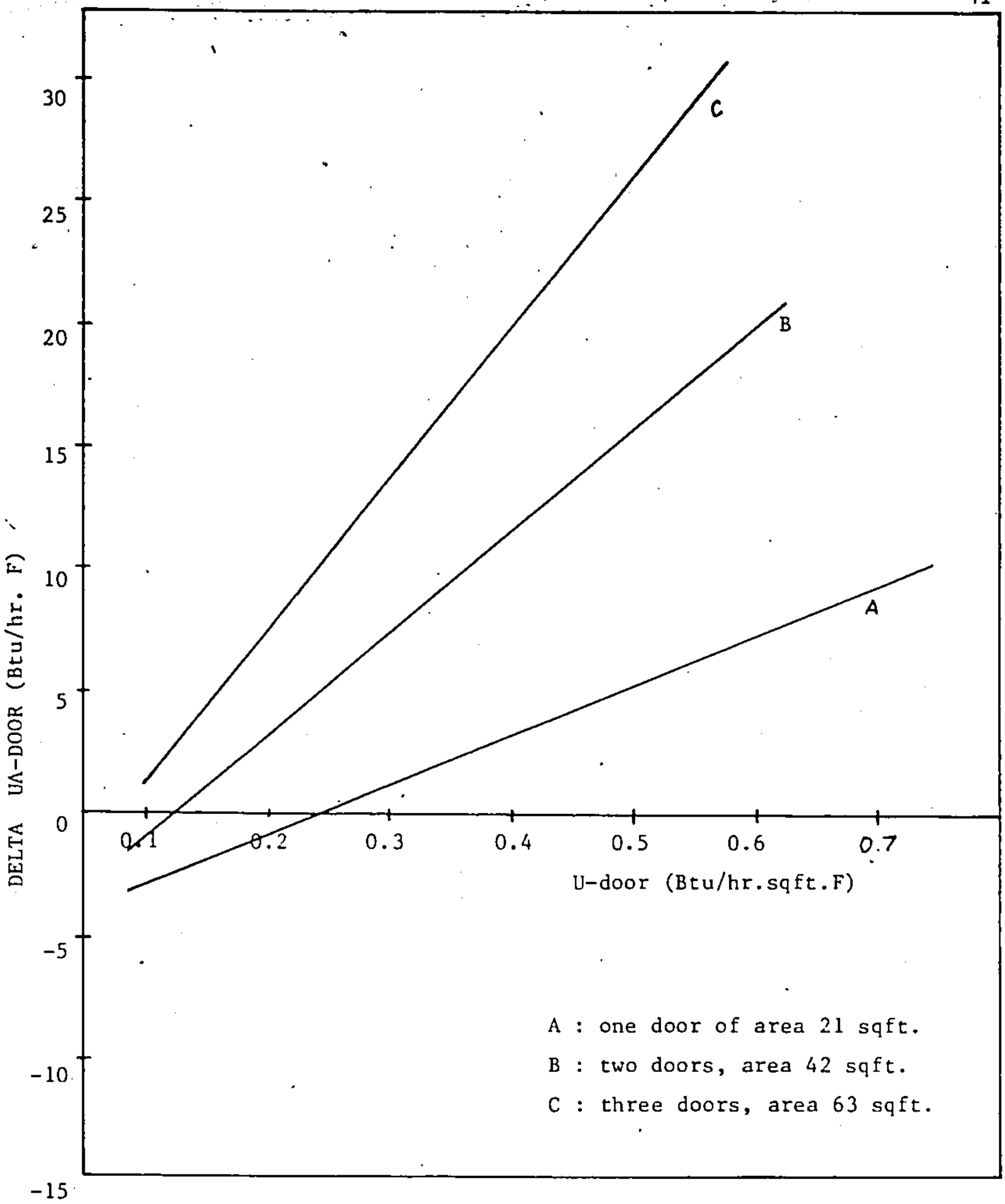

FIG. 3.3 Graph to determine Delta UA-door for different U-values and door areas

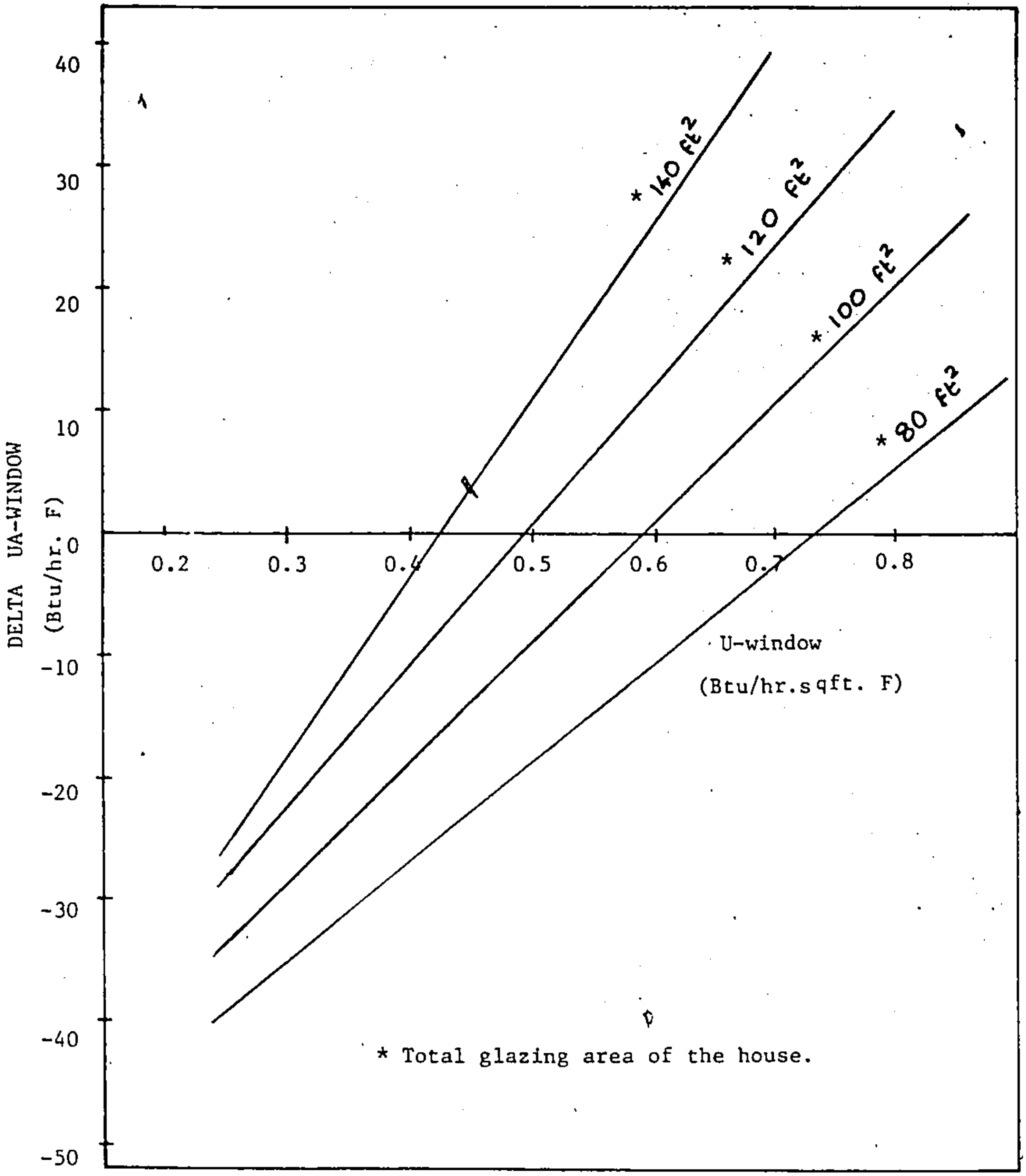

FIG. 3.4 Graph to determine Delta UA-window for different U-values and glazing areas

achieved by having a double glazed window with 0.25 inch of air space. The U-values of the different types of windows can be obtained from Chapter 23 of ASHRAE 1981 Fundamentals (Ref 11). The graph shows curves for different window glazing areas. The datum on the ordinate corresponds to the UA-window of the base case house. The ΔUA-window can be determined by locating the U-window on the abscissa, drawing a vertical line to intersect the curve of the corresponding area, and reading off the ΔUA-window on the ordinate.

5. INFILTRATION : The leakage characteristic of a house envelope was represented as a leakage number. The LN for the base case house was 2.2. The infiltration into the house was then determined by using the design weather conditions for Windsor obtained from Chapter 24 of Ref 11. The infiltration obtained was then expressed as an effective 'UA' value as shown in appendix C. The LN value of the house can be determined by doing a fan depressurization test on the house (see appendix C).

Fig. 3.5 shows the graphs for determining the ΔUA-infiltration for both gas and electrically heated houses as a function of the LN of the house. The higher infiltration in the gas heated houses is due to the presence of a chimney (appendix C). The figure shows two curves for the two cases. Because of better construction practices and the building code requirements, it can be expected that the LN of new houses, in general, will be less than 2.5. Therefore the

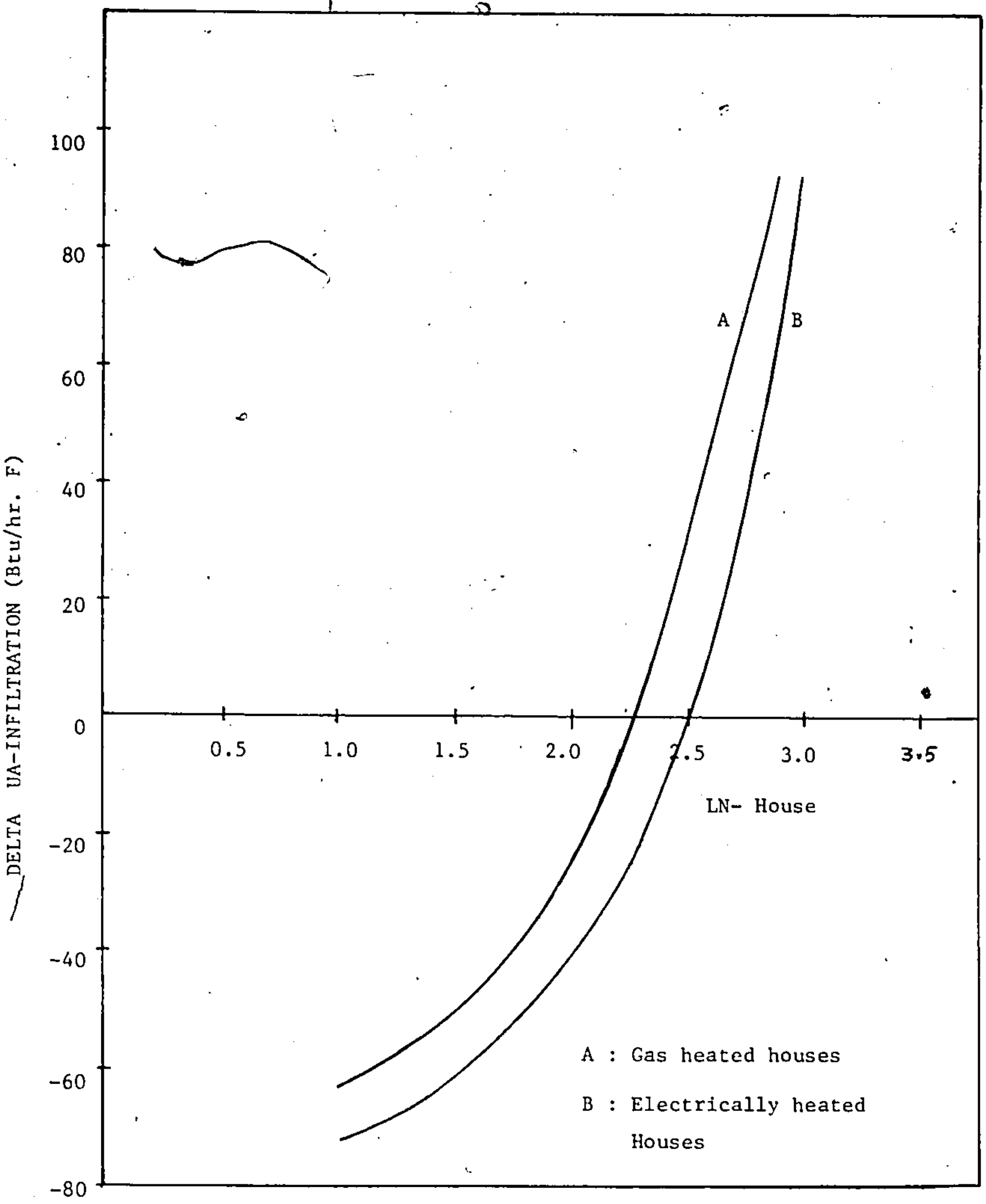

FIG 3.5 Graph to determine Delta UA-infiltration

graph in Fig. 3.5 does not show the curves extending beyond an LN of approx. 2.7. To determine the ΔUA-infiltration of the house, locate the LN of the house on the abscissa. Draw a vertical line to intersect the pretinent curve, and read off the corresponding ΔUA-infiltration from the ordinate.

The above five graphs cover all the components of a house with an unheated basement. For any house, the sum of the ΔUA values obtained from these graphs gives an overall ΔUA relative to the BLC of 238 Btuh/F of the base case house.

The graphical presentation of the component analysis has several advantages over a tabular presentation. The most important advantage is that interpolation can be done easily for areas or R-values not listed in a table. This is more evident for components like walls, ceiling and infiltration where the curves are not linear, and hence interpolation using tables will be cumbersome.

The second advantage is the ease with which the graphs can be modified for datum values other than those shown for the various components. If, for example, the optimum R-value of walls is different from R-21 of the base case house, the coordinate system can be displaced so that the abscissa intersects the curve representing an area of 1000 sq.ft. at the new R-value. Thus the same graphs can be used with minor modifications for locations other than Windsor where the optimum parameters of the base case house will be different from that determined for Windsor.

3.2.3 SECTION III

The ΔUA of the house can be calculated from the previous two sections. Analysing the ASHRAE degree day equation (eq. 3.3), it can be seen that the annual heating load of a house can be determined if the corresponding ΔDD of the house is known. This section describes the method developed to determine the ΔDD of a house once the ΔUA is known.

To analyze the relationship between ΔUA and ΔDD for a house, if any, the base case house was modified to obtain different ΔUA values for the house. The corresponding ΔDD values were obtained from the CIRA simulation results (Table 3.3). Fig. 3.6 shows the relation between ΔDD and ΔUA for a house obtained from the analysis of the CIRA results. The abscissa represents the ΔUA of the house, and the ordinate represents the ΔDD of the house. The datum for the abscissa is the BLC of the base case house, i.e. BLC=238, while the datum for the ordinate is the variable base degree days of the base case house, i.e. DD=3096. The graph was obtained for the city of Windsor and for constant internal and solar gains. The graph shows that the variable base DD of the house increases as the building load coefficient of the house increases. As the annual heating load is directly proportional to the degree days, the graph indicates, indirectly, that the annual heating load of the house increases when the building load coefficient is increased. The solar gains were kept approximately constant

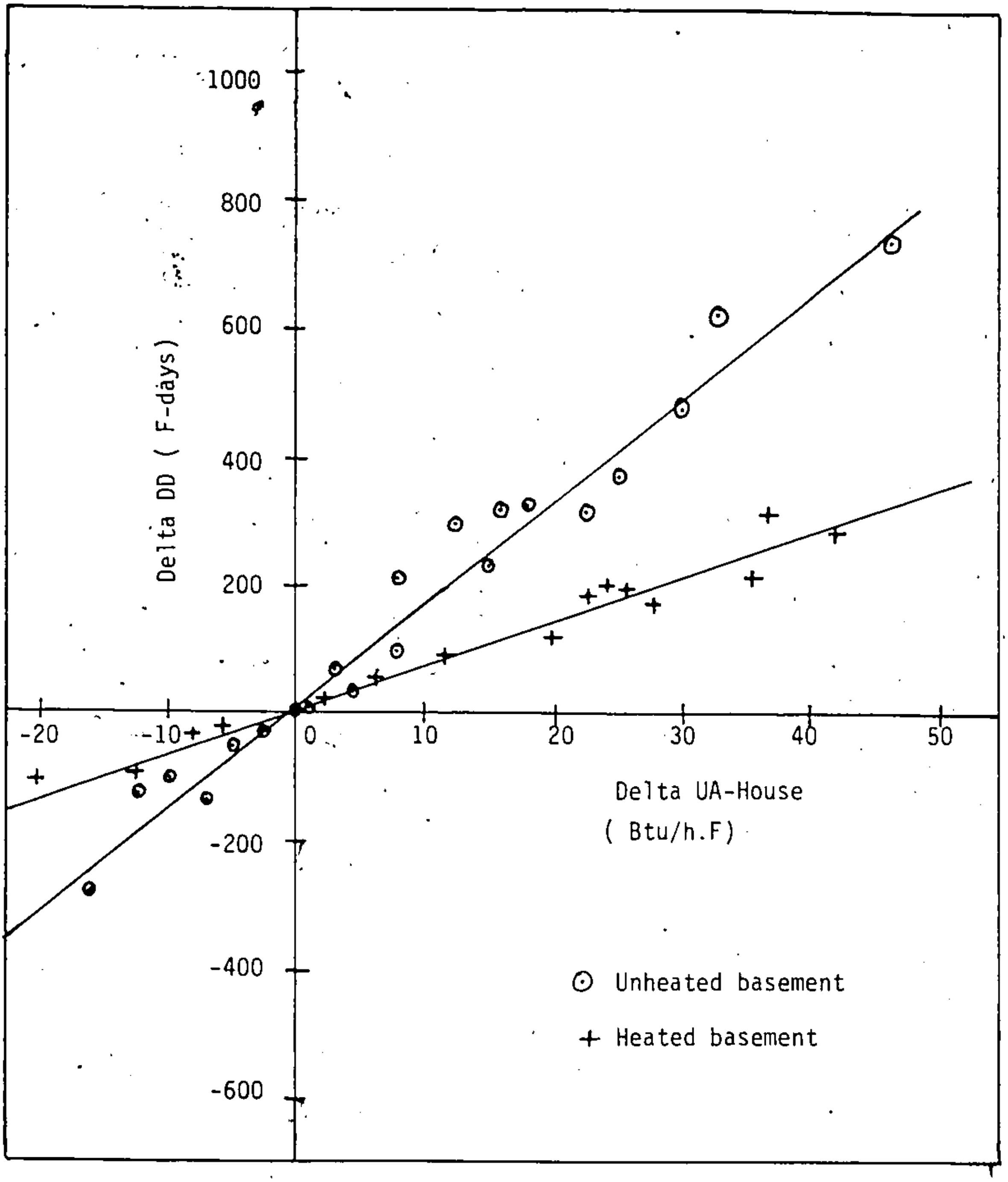

FIG 3.6 Relationship between delta DD and delta UA of a house for constant internal and solar gains

TABLE 3.3

Summary of DD and UA values from CIRA simulations

CASE I Unheated basement		CASE II Heated basement	
ΔUA	ΔDD	ΔUA	ΔDD
46.6	730	42.7	287
33.1	623	37.3	309
31.1	471	36.2	212
25.2	371	28.3	186
22.6	312	26.2	195
18.2	326	24.6	201
15.2	230	23.1	185
16.0	321	20.6	121
12.4	300	12.1	91
7.9	215	6.6	56
7.8	94	2.5	26
6.5	62	0.0	0
4.7	35	-5.5	-22
0.8	12	-7.6	-31
0.0	0	-12.1	-92
-2.6	-26	-20.1	-108
-4.8	-51	-	-
-7.2	-136	-	-
-9.4	-99	-	-
-12.7	-117	-	-
-16.3	-286	-	-

by keeping the glazing area on the South, West and East sides unchanged. From the graph it can be seen that there is a linear relationship between ΔUA and ΔDD as obtained from the CIRA program.

Linear regression analysis was performed with the data obtained for ΔUA and ΔDD. The dependent variable was taken to be ΔDD, and the independent variable as ΔUA. The results are shown in Table 3.4. A straight line fit was obtained between ΔUA and ΔDD. The curve that was fit to the data was of the form:

$$\Delta DD = a + m * \Delta UA$$

where,

a is the constant when ΔUA is 0, and,

m is the slope of the straight line fit.

As the origin corresponds to the DD of the base case house, it was necessary to make the curve to pass as close to the origin as possible. This was achieved by inputting more than one data set point for the coordinates of the origin, thereby forcing the line to pass as close to the origin as possible. The slope of the curve was 16 and the constant was 18. A coefficient of determination of 0.975 was obtained from the regression analysis.

The graph shows the change in the DD of the house when the BLC is changed from that of the base case house. Knowing the ΔUA of the house from the previous two sections, the corresponding ΔDD can be read off from the graph. Similar

TABLE 3.4

Regression Analysis Results for the Base Case House

<u>CASE I : Unheated basement</u>-

Equation used : $\Delta DD = a + m * \Delta UA$

Coefficient of Determination = 0.975

Constant on the ordinate = 18 F-days

Slope m of the linear fit = 16

<u>CASE II : Heated basement</u>-

Equation used : $\Delta DD = a + m * \Delta UA$

Coefficient of Determination = 0.983

Constant on the ordinate = 3.5 F-days

Slope m of the linear fit = 7

results were obtained for the base case house with a heated basement (see table 3.4 and Fig. 3.6).

Analysing eq. 3.1 it can be seen that the modified degree day value is a constant for a given location. Though it was found that the value of the empirical factor C_D can vary from house to house even in a given location (Chapter 28, Ref 11), no method was suggested to determine the actual degree days of a house in a given location. The graph in Fig. 3.6 shows that it would be incorrect to use one single value for the correction factor C_D for all houses in a location. The balance-point temperatures can vary from house to house, and as a result, the energy consumption for heating also will vary. The graph developed shows a method to determine the energy consumption of a house in a particular location, in this case Windsor.

In the previous analysis the solar gains were kept approximately constant by keeping the glazing area on the South, West and East sides unchanged. The linear relation obtained does not give accurate results when the glazing area on these sides is changed. This is because of the fact that the effect on the heating load of increasing the glazing area is two-fold. When the glazing area is increased, the wall area is decreased by an equal amount. As the U-value of the glazing is greater than that of the wall replaced, the net effect is to increase the overall UA of the house. This results in an increased conduction loss.

The corresponding increase in the DD of the house can be determined from Fig. 3.6 once the increase in the UA of the house is known.

The second effect of increasing the glazing area is to increase the solar gains into the house. This increased solar gain, especially on the South side, is generally high enough to offset any increase in the conduction losses mentioned above. In some cases the solar gains may even reduce the heating load of the house (Ref 19). Thus when the glazing area is increased, Fig. 3.6 shows an increase in the DD of the house, while it is actually decreased. It should, however, be noted that a decrease in the DD of the house does not necessarily mean a decrease in the annual heating load of the house. The annual heating load is a function of both the DD and the building load coefficient of the house.

In order to take into consideration the change in solar gains, the effect of changing the glazing area on the South, West and East sides on the DD of the house was analyzed. The glazing area was varied from that of the base case house while keeping the other components like walls and ceiling areas and R-values unchanged. To begin with, the window area on the South side was changed from 25 sq.ft. of the base case house, and the DD and the BLC of the house were obtained from the CIRA output. Several CIRA runs were made for different south glazing areas. The above analysis was performed for the following four cases:

1. Single glazing on the South side.
2. Double glazing on the South side.
3. Single glazing on the East (or West) side, and
4. Double glazing on the East (or West) side.

Table 3.5 shows the summary of the CIRA output results for double glazing on the South and East sides. The first column shows the change in the window area. The ΔUA is the corresponding change in the BLC of the house. The actual ΔDD shown in the third column is the change in the DD of the house due to the change in the glazing area. It can be seen that the DD of the house has decreased when the glazing area is increased. If only Fig. 3.6 were used, a positive ΔDD would have been obtained for the same change in glazing area. This 'spurious' change is shown in the fourth column. This change has been termed 'spurious' for it is not the actual change in the DD of the house. This value will always be positive as long as there is a positive change in the BLC of the house. The modified ΔDD shown in the last column is the difference between the actual ΔDD and the spurious ΔDD. In other words, this is the error induced if only Fig. 3.6 was used to determine the ΔDD of the house without applying any correction to it. The sum of the modified ΔDD and the spurious ΔDD gives the actual ΔDD for any glazing area. The modified ΔDD is the correction that has to be applied to the ΔDD obtained from Fig. 3.6.

TABLE 3.5

CIRA Results for South and East Window Glazings

Glazing Area (sq.ft.)	ΔUA	Actual ΔDD	Spurious ΔDD	Modified ΔDD
SOUTH DOUBLE GLAZING :				
0	-18.2	189	-265	454
25	0.0	0	0	0
35	7.2	-18	110	-128
50	18.1	-43	272	-315
75	36.2	-78	543	-621
100	54.2	-111	813	-924
150	90.2	-166	1353	-1519
EAST DOUBLE GLAZING :				
0	-18.2	-41	-265	224
25	0.0	0	0	0
35	7.2	13	110	-97
50	18.1	34	272	-238
75	36.2	63	543	-480
100	54.2	88	813	-725
150	90.2	129	1353	-1224

Fig. 3.7 shows the correction to be applied to Fig. 3.6. The abscissa is the glazing area on the South facing side. ordinate is the modified ΔDD obtained from Table 3.5. The figure shows two curves one for single and one for double glazed windows. Fig. 3.8 shows the graphs for single and double glazed windows for the East or West sides.

In order to obtain the ΔDD of any house, determine the ΔUA of the house from the first two sections. Using this ΔUA determine the ΔDD from Fig. 3.6. Then, knowing the window areas on the South, East and West sides of the house, determine the ΔDD from Figs. 3.7 and 3.8. The sum of these three ΔDD values gives the actual ΔDD of the house. The heating load of the house can now be calculated using equation 3.3.

In order to investigate the effects of the weather conditions on the relationship between ΔDD and the ΔUA of a house, the analysis done for Windsor was repeated for the city of Ottawa. The optimum R-values for walls and ceiling were calculated using the equations as shown for Windsor in appendix B. The optimum R-values for walls and ceiling were calculated as R-26 and R-31 respectively. The windows were assumed to be double glazed. The areas of the different components were the same as for the base case house in Windsor. The analysis was done for the unheated basement house. The weather file in the program for Ottawa was used to calculate the annual heating variable base degree days

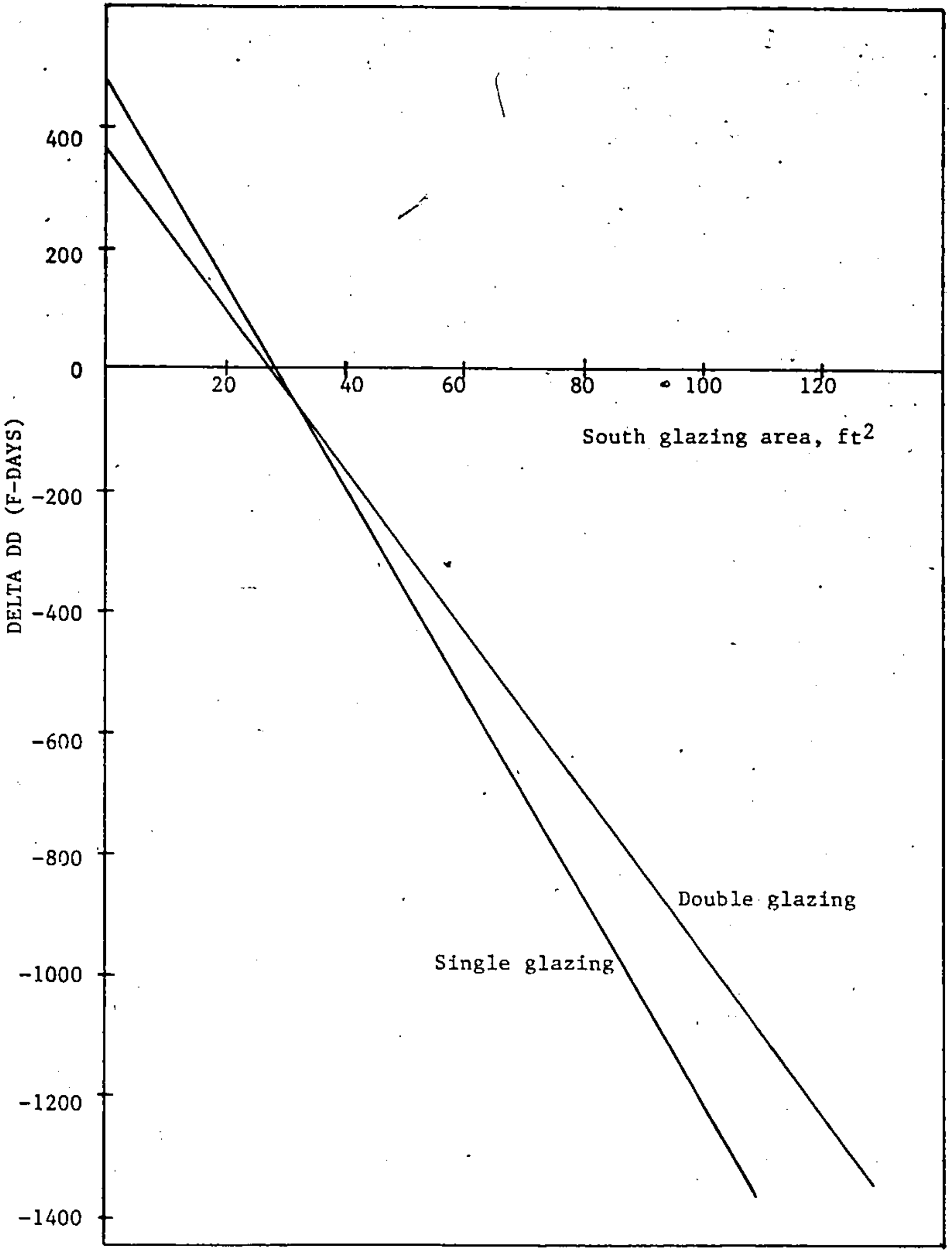

FIG. 3.7- Correction to be applied to Fig. 3.6 for a change in South glazing area

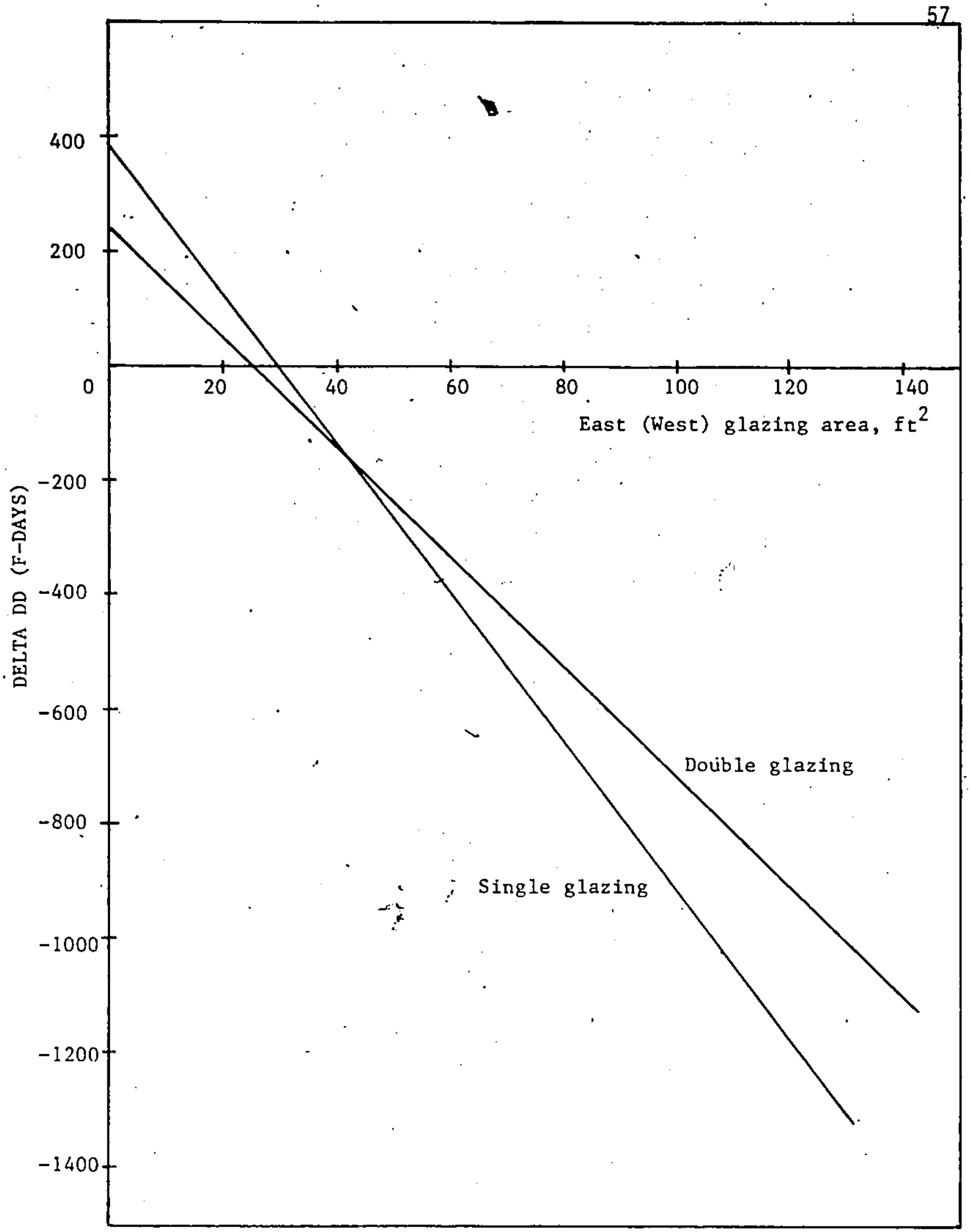

FIG. 3.8- Correction to be applied to Fig. 3.6 for a change in East (West) glazing area

and the annual heating load of the house. The variable base DD of the base case house was determined as 5873 F-days and the BLC as 219.

Table 3.6 summarizes the results of the linear regression analysis performed on the data for Ottawa. The slope of the curve was obtained as 14 and the constant on the ordinate was -2. The coefficient of determination was obtained as 0.997. The high value of this coefficient shows that the relation between ΔDD and ΔUA for Ottawa is essentially linear(see Fig.3.9). Observe that the slopes of the curves for Windsor and Ottawa are very close to each other. This suggested an analysis of the combined data for both the locations. Regression analysis results obtained for the combined data are shown in Table 3.6. The coefficient of determination obtained was 0.971 and the slope of the curve was approximately 15. The results indicate a possibility of using a single curve for both Windsor and Ottawa. Fig. 3.9 shows the graphs for all the three cases, viz. for Ottawa, Windsor, and for the combined data of the two locations. It should, however, be noted that though the same curve could perhaps be used for the two locations, the datum values for the two locations are not the same. It is simple to determine the BLC of the base case house for different locations once the optimum values for the different components are known. Further research will perhaps be required to determine the variable base DD of the base case house in different locations.

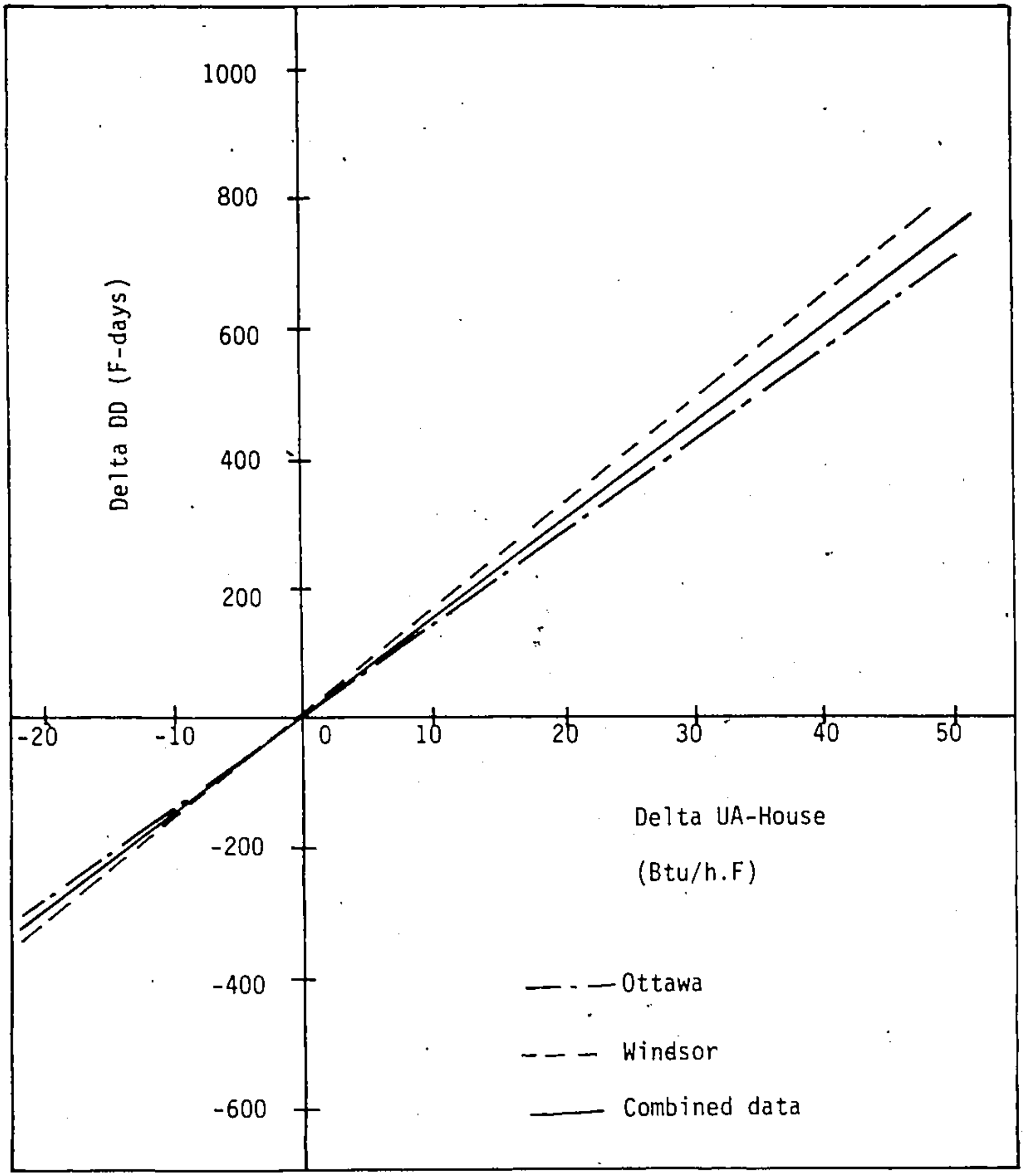

FIG 3.9 Relationship between delta DD and delta UA for combined data for Ottawa and Windsor

TABLE 3.6

Regression Analysis Results for Ottawa

Results for Ottawa:

Variable base degree days = 5873 F-days

Building Load Coefficient = 219 Btu/h.F

Equation used : $\Delta DD = a + m * \Delta UA$

Coefficient of Determination = 0.997

Slope of the curve, m = 14

Constant on the ordinate = -2 F-days

Results for Windsor and Ottawa combined:

Coefficient of Determination = 0.971

Slope of the curve = 15

Constant on the ordinate = 10 F-days

The energy rating of the house can be determined by comparing the heating load of the house with that of the base case house. This was done by first 'normalizing' the heating load of the house by dividing by the floor area of the house. A larger house will have a higher heating load compared to a smaller house. Thus, if the energy rating is based on the heating load only, then larger houses may receive a poorer rating compared to a smaller house. To avoid penalizing a house for its' size, normalization of the heating load was done. The following relation was used to determine the rating of a house:

$$\text{Energy Rating} = \left[(\text{NHL})_{opt} - (\text{NHL})\right] / (\text{NHL})_{opt}$$

where,

NHL = normalized annual heating load of the house,

$(\text{NHL})_{opt}$ = normalized annual heating load of the base case house.

Thus, a house with a positive rating is better than the base case house. The energy rating can be expressed as a percent instead of a ratio as shown above. Comparing the annual heating loads instead of the annual energy consumption of the house avoids the necessity of assuming an efficiency for the heating system to determine the energy rating of the house. A house with an electric resistance heating system may consume less energy because of a higher system efficiency compared to a house with a gas heating system. As the objective of this was to rate the energy performance of the house envelope only, the energy rating was expressed as shown above. Fig. 3.9 shows the graphical representation of the above equation. The abscissa is the annual heating load per unit floor area of the house. The ordinate is the energy rating of the house relative to the base case house, expressed as a percentage. The base case house is rated as 0. Once the annual heating load of the house has been determined from the three previous sections of the model developed, the energy rating can be found from this graph.

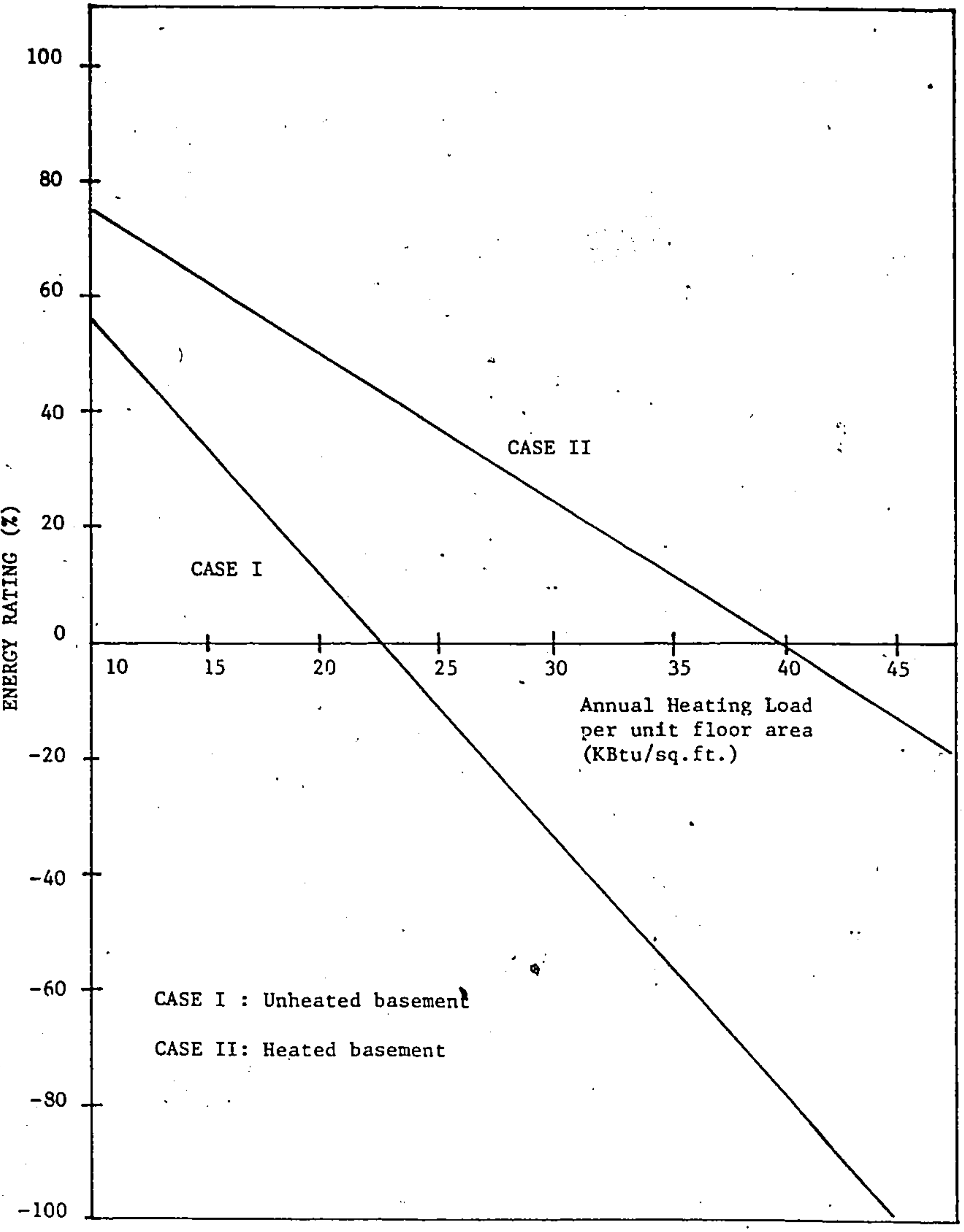

FIG 3.10 Graph to determine the Energy Rating (%) from the annual heating load per unit floor area of the house

Chapter IV

VALIDATION OF THE ENERGY RATING SYSTEM

In this chapter the results of the comparison of the actual energy consumption of three houses with the energy consumption predicted by the model developed are presented. The houses were all located in Windsor. The first house was a single story house with a partially heated basement while the other two houses were two-story houses with full basements.

4.1 COMPARISON OF RESULTS FOR THE SINGLE STORY HOUSE

A single story house with a partially heated basement was first chosen to validate the model. The house was an occupied, single family house located in Windsor. The floor area of the house was 1007 sq.ft. The windows were single-glazed with exterior aluminium storm windows. A natural gas-fired forced-air furnace provided the heating in the building. The structural details of the house are summarized in Table 4.1. There were three occupants in the house. The thermostat set-point was 70°F with no night set-back (see Ref 15 for more details of the house and its simulation in the DOE 2.1 energy simulation program). The measured annual energy consumption for space heating was 91.8 MBtu. The steady-state furnace efficiency as obtained

TABLE 4.1

Structural Details of the Single Story House

Type	: single story house with basement
Floor area	: 1007 sq.ft.
Exterior walls	: 2 X 4 stud construction with R-7 insulation
Ceiling	: R-40 insulation
Windows	: single glazing with exterior aluminium storms
HVAC System :	
Controls	: 70°F heating set-point, no night set-back
Heating equipment	: gas-fired forced air furnace
Occupants	: 3 people

TABLE 4.2

Comparison of Actual and Predicted Energy Consumptions

Single-story House:

Measured annual heating energy consumption of the house	= 91.8 MBtu
Steady-state efficiency of the gas furnace	= 70%
Annual heating load of the house	= 48.2 MBtu
Predicted annual heating load of the house	= 49.32 MBtu
Percentage difference between the actual and predicted annual heating load of the house	= 2.3%

from the nameplate was 70% (Ref 15). The basement was partially heated to a temperature of 60°F. The house was also simulated on the CIRA program (Ref 16) and the building load coefficient was determined as 384 Btu/h.F. The annual heating load of the house as calculated by the program was 48.2 MBtu.

For the purpose of validating the model developed, the house was assumed to have a fully heated basement. The results of this comparison are summarized in Table 4.2. The predicted annual heating load was 49.32 MBtu. The agreement was within 3%.

4.2 COMPARISON WITH THE VILLAGES OF RIVERSIDE HOUSE

The Villages of Riverside house is actually the average utility-measured performance of a group of 75 similar houses in one sub-division (Ref 18). The structural details and the energy consumption of the 75 houses were analyzed, and the data averaged out to eliminate the occupant-related effects. The house can therefore be regarded as an actual house. These details are summarized in Table 4.3. The house had an unheated basement, and the building load coefficient of the house was determined to be 351 Btu/h.F. The house was simulated on the CIRA program (Ref 16) and the annual heating load was determined to be 40.06 MBtu. The internal gains were estimated to be 70,000 Btu/day. The results of

TABLE 4.3

Details of the Villages of Riverside House

Type	: two story house with unheated basement
Floor area	: 962 sq.ft.
Exterior wall area	: 897 sq.ft.
Ceiling area	: 481 sq.ft.
Exterior walls	: R-11 insulation
Ceiling	: R-22 insulation
Windows	: double glazed
HVAC System:	
Controls	: 70°F heating set-point with no night set-back
Heating equipment	: electric baseboard
Occupants	: 4 people

TABLE 4.4

Comparison of Actual and Predicted Energy Consumptions

Villages of Riverside House :

Annual energy consumption for space heating = 40.06 MBtu

Estimated internal gains = 70,000 Btu/day

Annual heating load = 40.06 MBtu

Predicted annual heating load of the house = 42.42 MBtu

Predicted annual heating energy consumption = 42.42 MBtu

Percentage difference between actual and predicted energy consumption of the house = 5.8%

the comparison of the annual heating load predicted by the model with the actual annual heating load are shown in Table 4.4. The agreement was within 6%.

4.3 COMPARISON OF RESULTS FOR THE TWO STORY HOUSE

The third house was a two story house, also located in Windsor. The house was occupied, and was heated by a natural gas forced-air furnace located in the basement. The floor area of one floor of the house was 704 sq.ft. The structural details of the house are summarized in Table 4.5. The walls were of frame wall construction and had an R-12 insulation. The insulation on the ceiling was R-12. The windows were distributed mostly on the East and West sides. The window area on the East side was 94 sq.ft. and on the West side was 72 sq.ft. The window area on the North was 11 sq.ft. and on the South was 3 sq.ft. The windows were double glazed.

The thermal performance of the house was monitored over the 1982-83 winter season. The annual energy consumption for heating was obtained from the utility bills maintained by the homeowner by subtracting the energy used for hot water heating. This was calculated as 80 MBtu. (see Ref 17). The house was simulated on the CIRA program and the building load coefficient was determined as 533 Btu/h.F. The energy consumption predicted by CIRA was found to be in good agreement with the actual energy consumption of the house.

From the simulation results of this study , the seasonal furnace efficiency and the internal gains were estimated to be 75% and 144,000 Btu/day respectively. The steady-state bonnet efficiency of the furnace was 80%. (see Ref 17 for for more details on the monitoring and simulation of the house on the DOE 2.1 and CIRA energy simulation programs).

In order to validate the model developed in this study with the actual energy consumption of the house, the house was simulated again on the CIRA program with some modifications. Note that the internal gains in the house are greater than that assumed in the model (60,000 Btu/day) by a factor of 2.5. Because of such high internal gains, the actual energy consumption of the house will be lower than that predicted by the model. It was therefore decided to simulate the house on CIRA with reduced internal gains. The internal gains were reduced to a value close to 60,000 Btu/day. The annual heating energy consumption of this modified house was determined to be 100.4 MBtu. The annual space heating load was 75.3 MBtu. The annual space heating load was then determined using the model developed. The results are summarized in Table 4.6. The agreement between the predicted and the modified annual space heating load was within 6%.

The justification for modifying the internal gains of the house lies in the fact that most houses may not have such high internal gains as this house. The high internal gains of this house could be an exception rather than the rule. The comparison also brings out the limitation of the model.

TABLE 4.5

Structural Details of the Two Story House

Type	single family, detached two story house with a full heated basement
Floor area	704 sq.ft. (one floor only)
Exterior wall area	1836 sq.ft.
Exterior wall	R-12 insulation
Ceiling	R-12 insulation
Windows	double glazed
Window areas	92 sq.ft. on East side
	74 sq.ft. on West side
	15 sq.ft. on North side
	3 sq.ft. on South side
HVAC System:	
Controls	70°F thermostat set-point, no night set-back
Heating equipment	gas-fired forced air furnace
Cooling equipment	central air-conditioning
Occupants	5 people

TABLE 4.6

Comparison Results for the Two Story House

Measured annual energy consumption of the house	: 80 MBtu
Estimated internal gains	: 144,000 Btu/day
Annual energy consumption of the house for modified internal gains	: 100.4 MBtu
Annual heating load for the modified house	: 75.3 MBtu
Predicted heating load	: 70.9 MBtu
Percentage difference between the modified and predicted annual heating load of the house	: 5.85%

4.4 LIMITATIONS

Despite the good agreement found between the actual and the predicted annual heating loads for the above houses, there are some limitations of the energy rating system. As the rating system was restricted to the analysis of the building envelope only, the internal gains were assumed to be constant. Hence, if the internal gains are very much different from those assumed, the heating load predicted by the system will be different than the actual heating load.

This limitation was apparent when the model was validated against the two story house which had internal gains more than those assumed. The limitation could be considered unimportant by the reasoning that the main objective of the energy rating system is to arrive at a rating of the building envelope. Thus the assumption of a fixed internal gain becomes one of the standard 'building operating conditions' for the house.

The second limitation of the rating system is that it cannot determine the energy consumption of passive solar houses accurately. The rating system was developed by simulating a 'typical' single family house on CIRA. Thus any house which does not conform to this classification cannot be modelled accurately using this system. Also, the CIRA energy simulation program does not simulate accurately houses which have high passive solar gains. The discrepancy between the CIRA predicted energy consumption and the actual energy consumption was found to be high for houses of unusual designs (Ref 17). Thus the energy rating system will not give reliable results for such houses.

The model used for representing the infiltration component was developed in an earlier study (Ref 10). This model, it was found, gave accurate results for houses located in an urban location. All the restrictions applicable to this model will, therefore, apply to the energy rating system. If the contribution of infiltration is only a small fraction of the total building heat loss, the rating system could perhaps be used for other types of locations without sacrificing accuracy significantly. This assumption will not be true for houses with high infiltration.

Chapter V

CONCLUSIONS AND RECOMMENDATIONS

The concept of having energy labels to indicate the thermal performance of the building envelope is still not in use in Canada. This study is the first step in the process of developing an energy rating system that could be used to rate the thermal performance of the building envelopes of residential houses.

The conclusions of this study are:

1. A simple model to predict the annual space heating load of a new residential building was developed using the CIRA 1.c building energy simulation program. The model was developed for a single family house located in Windsor, Ontario, Canada.
2. The energy rating system was developed as an extension of the above model. The energy rating system determines the energy rating of the building envelope of the house compared to the optimum house of the location. The energy rating system was developed for the Windsor location using the optimum house for Windsor.
3. An Energy Label for a house is a very useful and practical concept. By adopting such a system, a

building performance standard that will be energy efficient can be developed. A sample format of an Energy Label has been presented in this study.

4. The accuracy of the model was verified by comparing the predicted annual heating load with the actual annual heating loads of three houses located in Windsor. The agreement was within 6% for all the houses.
5. It was found that the relation between the variable base degree days and the building load coefficient of a house in any location, expressed with respect to the optimum house of that location, remains approximately the same as determined for Windsor. This was verified by performing the analysis for the City of Ottawa. However, this relation should also be tested for other locations in Canada.

Based on the information obtained in this study, the following recommendations are made:

1. The energy rating system was developed for constant internal gains. Further research would be required to determine the effects of occupants and equipment on the annual space heating load as predicted by the model developed.
2. The analysis done for Windsor should be extended for other locations in Canada. It was found in this study that a single energy rating system could be used for

a group of closely located cities rather than developing an energy rating system for each location. Further studies will be required to explore this possibility.

3. It is recommended that research be carried out to determine a functional relationship between the annual heating degree days and the base temperature for various locations in Canada. Such an equation will be useful in both hand and computer calculations for determining the energy consumption of houses. As a part of such a study, research could be done to determine the balance-point temperatures of houses with different characteristics.
4. The models used for infiltration and basement heat losses are not fully developed and could lead to inaccuracies. These possible inaccuracies could in turn affect the accuracy of the rating. More accurate models should be developed for these components.
5. The energy rating system should be further validated against actual data to gain confidence in the system.

REFERENCES

1. Rosenfeld, A.H., 'Building Energy Labels for New and Existing Residential and Commercial Buildings'. Building Energy Analysis Group, Energy and Environment Division, Lawrence Berkeley Laboratory, University of California. July 1981.

2. Tarini, Eric, 'A Methodology for Adding a Home Energy Rating to an Existing RCS Audit Program'. Energyworks Inc., Massachusetts. 1983

3. Energy Conservation Rating System : For New, Single Family Detached Residences in Minnesota. Building Energy Analysis Group, Energy and Environment Division, Lawrence Berkeley Laboratory, University of California, 1981.

4. Colborne, W. G., 'The Case for a Building Rating System (Energy Labels)'. Personal communication.

5. Blancett, Robert S., 'A Method of Rating the Thermal Efficiency of a House Envelope Relative to an Energy Efficient Standard'. Proceedings of the ASHRAE/DOE-ORNL Conference, December 3-5, 1979.

6. Rogers, J. T., Findlay, J.B., et.al.,'The Equivalent Degree-Day Concept for Residential Space Heating Analysis'. CIB proceedings of the Second International CIB Symposium on Energy Conservation in Built Environment: Danish Building Research Institute, Copenhagen 1979.

7. Energy Performance of Building Group. CIRA 1.0 Reference Manual, March 1982. University of California, Lawrence Berkeley Laboratory.

8. Evaluation of the Cost Effectiveness of Electrical Energy Conservation in Canada. ICF Incorporated, 1850 K Street, Northwest Suite 950, Washington, D.C. 20006. September 1982.

9. Measures for Energy Conservation in New Buildings, 1978. Ottawa: Associate Committee on the National Building Code, National Research Council of Canada.

10. Ahmed, Osman, 'An Approach to Develop a Simplified Infiltration Model for Residential Buildings'. Master's thesis, Dept. of Mechanical Engineering, University of Windsor, Windsor, Canada. 1983.

11. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 'ASHRAE Handbook of Fundamentals'. 1981 edition.

12. Philips, R.K., Gordon, M.C., Linquist, E.G., 'A Simple Calculation for Obtaining the Number of Degree Days at Arbitrary Base Temperatures', Proceedings of the ASHRAE/DOE Conference: Thermal Performance of the Exterior Envelopes of Buildings II. Dec 6-9, 1982, Las Vegas, Nevada.

13. Guntermann, Alfred, 'A Simplified Degree Day Method for Commercial and Industrial Buildings', ASHRAE Transactions 87 (1981), 1:461-472.

14. Mitalas, G.P.,'Effect of Building Mass on Annual Heating Requirements'. CIB proceedings of the Second International CIB Symposium on Energy Conservation in Built Environment: Danish Building Research Institute, Copenhagen 1979.

15. Hall, J. D.,'A Retrofit Strategy for Two Canadian Residential Dwellings using the Building Energy Simulation Program DOE-2.1A'. Master's Thesis, Dept. of Mechanical Engineering, University of Windsor, Windsor, Canada. 1983.

16. Patwardhan, A. G., 'Critical Evaluation of CIRA'. Master's thesis, Dept. of Mechanical Engineering, University of Windsor, Windsor, Canada. 1984.

17. Ganesh, R., 'Residential Building Energy Analysis using Experimental Data : Monitoring, Modelling and Simulation'. Master's thesis, Dept. of Mechanical Engineering, University of Windsor, Windsor, Canada. 1984.

18. Colborne, W. G., Wilson, N. W., Hall, J. D., 'A Comparitive Study of Methods to Determine Annual Energy Consumption for Space Heating'. Solar Energy Society of Canada, Conference Proceedings, Volume I/II, University of Saskatchewan, Regina, Saskatchewan, Canada. August 23-29, 1982.

19. Steinmuller, B., Bruno, R., 'The Energy Requirements of Buildings'. Philips GmbH Forschungs Laboratorium Aachen, Aachen, Weibhausstr.

20. The Cost of Insulating Various Types of Building Assemblies. Scanada Consultants, Ltd. 436 MacLaren St., Ottawa, Ontario, K2P 0M8, Canada. August 1980.

Appendix A

SI EQUIVALENTS OF IMPERIAL UNITS

IMPERIAL UNITS	EQUIVALENT SI UNITS
1 ft.	0.305 m
1 inch	2.54 mm
1 sq.ft.	0.093 m
(t°F - 32) X 5/9	t °C
1 MBtu	293.25 KWH
1 Btu/h.F	0.53 W/°C
1 sq.ft.h.F/Btu	0.176 m °C/W
1 Btu/h.sq.ft.F	5.68 W/m °C
3906 Fahrenheit degree days	2170 Celsius degree days

Appendix B

CALCULATION OF OPTIMUM INSULATION LEVELS

The optimum insulation R-values for walls and ceiling can be determined by using the following relation (see Chapter 20, Ref 11):

$$R_{opt} = \sqrt{\frac{24 \times DD \times C_D \times FC \times PWF}{B \times \eta}}$$

where,

R_{opt} = optimum R-value, sq.ft. F.h./Btu

DD = degree days (base 65 F) of the location

C_D = an empirical correction factor

FC = fuel cost, \$/Btu

PWF = present worth factor

B = cost of additional insulation, $\$/ft^2/R$

η = seasonal efficiency of the heating system.

The present worth factor can be calculated by the relation:

$$PWF = \left(\frac{1 + fe}{d - fe}\right)\left[1 - \left(\frac{1 + fe}{1 + d}\right)^N\right]$$

where,

fe = fuel escalation rate above inflation

d = discount rate above inflation

N = economic lifetime of the house

Using the data shown in Table B.1, the optimum R-values were determined as follows:

Optimum R-value for wall insulation = 21 sq.ft.F.h./Btu
Optimum R-value for ceiling insulation = 26 sq.ft.F.h./Btu

The fuel prices were obtained from the Windsor Utilities Commission. The fuel escalation rates for gas and electricity were assumed to be 5% and 1% above inflation respectively. The cost of additional insulation for walls and ceiling varies depending on the source (Ref 8,15,20). These values were therefore assumed to be 5.9 ¢/sq.ft./R and 3.9 ¢/sq.ft./R for walls and ceiling insulation respectively. (See Ref 16 for more details on these factors). The economic lifetime of the house was chosen as 30 years. In general, longer lifetimes rather than shorter lifetimes are recommended to determine the optimum insulation levels (see Chapter 20, Ref 11).

TABLE B.1

Economic Details for Optimum R-value Calculations

Fuel Cost (Gas) = $5.75/MBtu

Fuel Cost (Electricity) = $13.18/MBtu

Fuel escalation rate (Gas) = 5% above inflation

Fuel escalation rate (Electricity) = 1% above inflation

Discount rate = 4% above inflation

Cost of additional insulation (Walls) = 5.9¢/sq.ft./R

Cost of additional insulation (Ceiling) = 3.9¢/sq.ft./R

Assumed seasonal efficiency of the gas furnace = 70%

Efficiency of electric baseboard heater = 100%

Economic lifetime of house = 30 years

Appendix C

INFILTRATION MODEL

Infiltration heat loss from a house can be as high as 25-30% of the total building heat loss. Therefore it is important to include this component in any model that predicts the energy consumption of houses.

Infiltration is a very complex phenomena that is dependent on many interacting variables. The model developed by Ahmed (Ref 10) determines infiltration as a function of the leakage characteristics of the house, the indoor-outdoor temperature difference and the outdoor wind speed. This model was used for rating the infiltration component in this study. The leakage characteristics of a house can be expressed as a Leakage Number LN ranging from 0.0 to 4.0. An LN=0.0 indicates that the house has a very tight structure while an LN of 4.0 indicates that the house structure is very leaky. An average house structure has an LN value between 2.0 and 2.5.

Once the LN of a house is known, infiltration can be determined using the relations developed in Ref 10. As the wind speed and the inside-outside temperature difference vary from day to day, it is necessary to assume some standard ΔT and wind speed so that all houses can be rated on the same basis. the design outdoor conditions for Windsor specified in Chapter 24 of Ref 11 were assumed to be the standard outdoor conditions.

The LN of a house can be determined by performing a simple door fan depressurization test on the house. The equation to be used is:

$$LN = 0.9802 - 0.427 \log(\Delta P)$$

for a Q/V ratio of 0.0610.(see Ref 10).

Here P is the pressure differential across the house structure, V is the volume of the house and Q is the air flow rate through the fan.

The infiltration models developed were:

CASE I : For gas heated houses-

$$I = 0.11 + \left[(1.91 \times 10^{-5})(e^{2.408LN})T(1+\epsilon \Delta T) + (2.3 \times 10^{-7}) \times (e^{2.391LN})W^2(1+\epsilon \Delta T) \right]$$

where I is in ac/h., and

$\epsilon = 0.001886$ is a constant.

CASE II : For electrically heated houses-

$$I = 1.3793 \times \left[(1.35 \times 10^{-5})(e^{2.4LN})I(1+\epsilon \Delta T) + (2.0 \times 10^{-7}) \times (e^{2.3LN})W^2(1+\epsilon \Delta T) \right]$$

Once the infiltration is known, the equivalent 'UA' due to infiltration can be determined using eq. 8, Chapter 25 of Ref 11-

$$UA = 0.018 \times V0$$

where V0 is the volume of outdoor air entering the building in cuft./h.

The volume of the base case house was 8000 cuft. In order to determine the UA-infiltration for any other house volume V1, multiply the the UA-infiltration of the base case house by the ratio V0/8000. The ΔUA-infiltration of the house can then be calculated by subtracting the UA-infiltration of the base case house from the UA-infiltration of the house.

Appendix D

BASE CASE HOUSE INPUT IN THE CIRA PROGRAM

The input is for the city of Windsor (Detroit TRY weather file). The following points regarding the input should be noted:

1. The inputs marked with an '*' are the default values of the program.
2. The input was prepared for the heating season analysis only. Therefore no cooling equipment was input. It was also assumed that there was no thermostat present and the indoor winter temperature was at a fixed value of 70°F.

```
Current answers for GENERAL named Podury :

   A) NAME of this house.......................? 'Podury'
   B) What CITY................................? 'Detroit'
   C) AZIMUTH of north face (degrees).........? '0' degrees
   D) What type of THERMOSTAT.................? 'None'
   E) Avg Indoor WINTER temperature (degF)....? '70' degF
   F) Avg Indoor SUMMER temperature (degF)....? '70' degF
   G) Total house FLOOR AREA (sqft)...........? '1000' sqft
   H) House MASS..............................? 'Light'
   I) Solar STORAGE factor (unitless).........? '.22' unitless
   J) SPECIFIC THERMAL MASS (Btu/Fsqft).......? '1.9' Btu/Fsqft*
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for ROOF-CEI named ROOF :

   A) NAME for attic/roof or ceiling..........? 'ROOF'
   B) Roof-Ceiling TYPE.......................? 'Unfinished attic'
   C) Insulation TYPE.........................? 'Fiberglass batts'
   D) Insulation THICKNESS (inches)...........? '8' inches
   E) Insulatable AIR SPACE (inches)..........? '12' inches
   F) Ceiling R-value (F-sqft/Btuh)...........? '26' F-sqft/Btuh
   G) Ceiling AREA (sqft).....................? '1000' sqft
   H) No. of ceiling VENTS (count)............? '5' count*
   I) No. of ceiling PENETRATIONS (count).....? '10' count*
   J) Ceiling sp. LEAKAGE area (sqin/sqft)....? '.0426251' sqin/sqft**
   K) Roof PITCH (%)..........................? '100' %
   L) Roof top MATERIAL.......................? 'Asphalt Shingles'
   M) Roof ABSORPTIVITY (%)...................? '95' %*
   N) Attic VENTILATION (cfm/sqft)............? '.5' cfm/sqft*
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for WALLS named West :

  A) NAME for the following walls............? 'West'
  B) Which wall ORIENTATION..................? 'West walls'
  C) Wall TYPE...............................? 'Two by Six Frame'
  D) Wall INSULATION.........................? 'Fiberglass batts'
  E) Insulation THICKNESS (inches)...........? '5.5' inches
  F) INSULATABLE wall THICKNESS (inches).....? '0' inches
  G) Exterior INSULATING SHEATHING...........? 'None'
  H) Wall R-VALUE (F-sqft/Btuh)..............? '21' F-sqft/Btuh
  I) Wall AREA wo/ windows & doors (sqft)....? '198' sqft
  J) No. of WINDOWS (No.)....................? '1' No.
  K) No. of VENTS in wall (No.)..............? '1' No.
  L) No. of other PENETRATIONS (No.).........? '1' No.
  M) Specific LEAKAGE AREA (sqin/sqft).......? '.0198839' sqin/sqft*
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

```
Current answers for WALLS named South :

  A) NAME for the following walls............? 'South'
  B) Which wall ORIENTATION..................? 'South walls'
  C) Wall TYPE...............................? 'Two by Six Frame'
  D) Wall INSULATION.........................? 'Fiberglass batts'
  E) Insulation THICKNESS (inches)...........? '5.5' inches
  F) INSULATABLE wall THICKNESS (inches).....? '0' inches
  G) Exterior INSULATING SHEATHING...........? 'None'
  H) Wall R-VALUE (F-sqft/Btuh)..............? '21' F-sqft/Btuh
  I) Wall AREA wo/ windows & doors (sqft)....? '288' sqft
  J) No. of WINDOWS (No.)....................? '2' No.
  K) No. of VENTS in wall (No.)..............? '1' No.
  L) No. of other PENETRATIONS (No.).........? '1' No.
  M) Specific LEAKAGE AREA (sqin/sqft).......? '.0187829' sqin/sqft*
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

```
Current answers for WALLS named North :

   A) NAME for the following walls...............? 'North'
   B) Which wall ORIENTATION.....................? 'North walls'
   C) Wall TYPE..................................? 'Two by Six Frame'
   D) Wall INSULATION............................? 'Fiberglass batts'
   E) Insulation THICKNESS (inches)..............? '5.5' inches
   F) INSULATABLE wall THICKNESS (inches).....? '0' inches
   G) Exterior INSULATING SHEATHING...........? 'None'
   H) Wall R-VALUE (F-sqft/Btuh)...............? '21' F-sqft/Btuh
   I) Wall AREA wo/ windows & doors (sqft)....? '310' sqft
   J) No. of WINDOWS (No.)....................? '2' No.
   K) No. of VENTS in wall (No.)..............? '1' No.
   L) No. of other PENETRATIONS (No.).........? '1' No.
   M) Specific LEAKAGE AREA (sqin/sqft).......? '.018' sqin/sqft*
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for WALLS named East :

   A) NAME for the following walls...............? 'East'
   B) Which wall ORIENTATION.....................? 'East walls'
   C) Wall TYPE..................................? 'Two by Six Frame'
   D) Wall INSULATION............................? 'Fiberglass batts'
   E) Insulation THICKNESS (inches)..............? '5.5' inches
   F) INSULATABLE wall THICKNESS (inches).....? '0' inches
   G) Exterior INSULATING SHEATHING...........? 'None'
   H) Wall R-VALUE (F-sqft/Btuh)...............? '21' F-sqft/Btuh
   I) Wall AREA wo/ windows & doors (sqft)....? '198' sqft
   J) No. of WINDOWS (No.)....................? '1' No.
   K) No. of VENTS in wall (No.)..............? '1' No.
   L) No. of other PENETRATIONS (No.).........? '1' No.
   M) Specific LEAKAGE AREA (sqin/sqft).......? '.0198839' sqin/sqft*
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for WINDOWS named East :

   A) NAME of the following windows...........? 'East'
   B) Which window ORIENTATION................? 'East'
   C) Window TYPE.............................? 'Double hung'
   D) GLAZING.................................? 'Double pane'
   E) DRAPES & SHUTTERS.......................? 'None'
   F) U-value (Btuh/sqft/F)...................? '.588' Btuh/sqft/F
   G) Average sash FIT........................? 'Average'
   H) Specific LEAKAGE AREA (sqin/sqft).......? '.0790502' sqin/sqft*
   I) Summer SOLAR GAIN factor (%)............? '77' % *
   J) Winter SOLAR GAIN factor (%)............? '77' % *
   K) Window AREA (sqft)......................? '25' sqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for WINDOWS named South :

   A) NAME of the following windows...........? 'South'
   B) Which window ORIENTATION................? 'South'
   C) Window TYPE.............................? 'Double hung'
   D) GLAZING.................................? 'Double pane'
   E) DRAPES & SHUTTERS.......................? 'None'
   F) U-value (Btuh/sqft/F)...................? '.588' Btuh/sqft/F
   G) Average sash FIT........................? 'Average'
   H) Specific LEAKAGE AREA (sqin/sqft).......? '.0790502' sqin/sqft*
   I) Summer SOLAR GAIN factor (%)............? '77' %*
   J) Winter SOLAR GAIN factor (%)............? '77' %*
   K) Window AREA (sqft)......................? '25' sqft
   L) Overhang PROTRUSION (inches)............? '24' inches*
   M) HEIGHT above top of window (inches).....? '12' inches*
   N) Average window HEIGHT (feet)............? '4.33' feet
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for WINDOWS named West :

   A) NAME of the following windows............? 'West'
   B) Which window ORIENTATION.................? 'West'
   C) Window TYPE..............................? 'Double hung'
   D) GLAZING..................................? 'Double pane'
   E) DRAPES & SHUTTERS........................? 'None'
   F) U-value (Btuh/sqft/F)....................? '.588' Btuh/sqft/F
   G) Average sash FIT.........................? 'Average'
   H) Specific LEAKAGE AREA (sqin/sqft)........? '.0790502' sqin/sqft*
   I) Summer SOLAR GAIN factor (%).............? '77' %*
   J) Winter SOLAR GAIN factor (%).............? '77' %*
   K) Window AREA (sqft).......................? '25' sqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for WINDOWS named North :

   A) NAME of the following windows............? 'North'
   B) Which window ORIENTATION.................? 'North'
   C) Window TYPE..............................? 'Double hung'
   D) GLAZING..................................? 'Double pane'
   E) DRAPES & SHUTTERS........................? 'None'
   F) U-value (Btuh/sqft/F)....................? '.588' Btuh/sqft/F
   G) Average sash FIT.........................? 'Average'
   H) Specific LEAKAGE AREA (sqin/sqft)........? '.0790502' sqin/sqft*
   I) Summer SOLAR GAIN factor (%).............? '77' %*
   J) Winter SOLAR GAIN factor (%).............? '77' %*
   K) Window AREA (sqft).......................? '25' sqft
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for DOORS named DOOR :

   A) NAME of following doors.................? 'DOOR'
   B) Door TYPE...............................? 'Plain (Hinged)'
   C) Door MATERIAL...........................? 'Wood Solid Core'
   D) Approximate Glass AREA (%)..............? '0' %
   E) Any STORM doors.........................? 'None'
   F) U-value (Btuh/sqft/F)...................? '.25' Btuh/sqft/F
   G) Door FIT................................? 'Average'
   H) Specific leakage AREA (sqin/sqft).......? '.0294501' sqin/sqft*
   I) Door AREA (sqft)........................? '21' sqft
   Y) ( DELETE this Component )...
   Z) ( Changes COMPLETED )...
```

```
Current answers for INFILTRA named Ventilation :

   A) Is there MECHANICAL Ventilation.........? 'None'
   B) NATURAL Cooling Ventilation.............? 'No'
   C) TERRAIN class...........................? 'Class 3'*
   D) SHIELDING class.........................? 'Class 3'*
   E) HEIGHT of living space (feet)...........? '8' feet
   F) Approx. house VOLUME (cubic feet).......? '8000' cubic feet
   G) HOW was leakage area MEASURED...........? 'Not measured'*
   Y) ( DELETE this Component )...
   Z) ( Changes COMPLETED )...
```

```
Current answers for LANDSCAP named Yard & Trees :

   A) Ground SURFACE TYPE.....................? 'Green grass'
   B) Ground REFLECTANCE (%)..................? '24' %*
   C) SOUTH solar EXPOSURE - DECEMBER (%).....? '60' %*
   D) SOUTH solar EXPOSURE - JUNE (%).........? '80' %*
   E) EAST solar EXPOSURE - DECEMBER (%)......? '60' %*
   F) EAST solar EXPOSURE - JUNE (%)..........? '80' %*
   G) WEST solar EXPOSURE - DECEMBER (%)......? '60' %*
   H) WEST solar EXPOSURE - JUNE (%)..........? '80' %*
   Y) ( DELETE this Component )...
   Z) ( Changes COMPLETED )...
```

```
Current answers for HVAC-SYS named Heat-Cool :

  A) What HEATING EQUIPMENT...................? 'Gas Furnace'
  B) Rated INPUT capacity (kBtu/hr)..........? '100' kBtu/hr
  C) Steady-state EFFICIENCY (%).............? '75' %
  D) FLUE gas temperature (degF).............? '250' degF
  E) What DISTRIBUTION system................? 'Forced Air'
  F) WHERE are pipes or ducts................? 'Basement'
  G) INSULATION on pipes or ducts............? 'None'
  H) Insulatable duct/pipe LENGTH (feet).....? '100' feet *
  I) Distribution LOSSES to outside (%)......? '25' %*
  J) What COOLING EQUIPMENT..................? 'None'
  K) Actual Fan FLOW (cfm)...................? '0' cfm *
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

```
Current answers for APPLIANC named FAMILY :

  A) NAME of occupants.........................? 'FAMILY'
  B) How many DAYTIME OCCUPANTS (people).....? '1' people
  C) How many NIGHT OCCUPANTS (people).......? '4' people
  D) DAILY hot water USE (gal/day)...........? '62.5' gal/day*
  E) WATER HEATER type.......................? 'Electric'
  F) Input RATING (kW).......................? '4' kW*
  G) Hot water THERMOSTAT setting (degF).....? '140' degF
  H) WHERE is water heater...................? 'Basement'
  I) Stdby/plumb. LOSSES (kBtu/hr)...........? '.423336' kBtu/hr*
  J) REFRIGERATOR type.......................? 'Auto. defrost & freezer'
  K) Average MONTHLY CONSUMPTION (kWh/mo)....? '100' kWh/mo
  L) DRYER and RANGE type....................? 'Both Electric'
  M) Internal MOISTURE generation (lb/dy)....? '3.79999' lb/dy*
  N) LIGHTS & OTHER HEAT GAINS (kBtu/hr).....? '1' kBtu/hr *
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

```
Current answers for SUBFLOOR named Basement :

   A) Subfloor NAME...........................? 'Basement'
   B) Subfloor TYPE...........................? 'Basement'
   C) Joist INSULATION........................? 'Polystyrene boards'
   D) Joist insulation THICKNESS (inches).....? '16' inches
   E) Total joist R-VALUE (F-sqft/Btuh).......? '82.0002' F-sqft/Btuh
   F) Floor AREA (Joists) (sqft)..............? '20' sqft
   G) No. of floor PENETRATIONS (No.).........? '10' No.
   H) Floor sp. LEAKAGE AREA (sqin/sqft)......? '.379751' sqin/sqft
   I) Subfloor WALL INSULATION material.......? 'Polystyrene boards'
   J) Wall insulation THICKNESS (inches)......? '4' inches
   K) Above-grade wall R-VALUE (F-sqft/Btuh)..? '30' F-sqft/Btuh
   L) ABOVE-Grade HEIGHT (feet)...............? '.11' feet
   M) Exposed PERIMETER (feet)................? '20' feet
   N) Soil CONDUCTIVITY (Btuh-in/F-sqft)......? '2.5' Btuh-in/F-sqft
   O) No. of WINDOWS (No.)....................? '0' No.
   P) No. of wall VENTS (No.).................? '5' No.
   Q) No. of wall PENETRATIONS (No.)..........? '10' No.
   R) Wall specific LEAKAGE AREA (sqin/sqft)..? '.5' sqin/sqft
   S) Below-grade R-VALUE (F-sqft/Btuh).......? '30' F-sqft/Btuh
   T) Floor R-VALUE (F-sqft/Btuh).............? '40' F-sqft/Btuh
   U) Eqv Floor RESIST' outs'd (F-sqft/Btuh)..? '100' F-sqft/Btuh
   Y) < DELETE this Component >...
   Z) < Changes COMPLETED >...
```

```
Current answers for SUBFLOOR named Basement**:

  A) Subfloor NAME............................? 'Basement'
  B) Subfloor TYPE............................? 'Basement'
  C) Joist INSULATION.........................? 'Heated basement'
  D) Total joist R-VALUE (F-sqft/Btuh).......,? '3' F-sqft/Btuh
  E) Floor AREA (Joists) (sqft)...............? '1000' sqft
  F) No. of floor PENETRATIONS (No.)..........? '10' No*
  G) Floor sp. LEAKAGE AREA (sqin/sqft).......? '.0379751' sqin/sqft*
  H) Subfloor WALL INSULATION material........? 'None' *
  I) Above-grade wall R-VALUE (F-sqft/Btuh)...? '9' F-sqft/Btuh
  J) ABOVE-Grade HEIGHT (feet)................? '1' feet
  K) Exposed PERIMETER (feet).................? '140' feet
  L) Soil CONDUCTIVITY (Btuh-in/F-sqft).......? '9.6' Btuh-in/F-sqft
  M) No. of WINDOWS (No.).....................? '0' No.
  N) No. of wall VENTS (No.)..................? '5' No*
  O) No. of wall PENETRATIONS (No.)...........? '10' No*
  P) Wall specific LEAKAGE AREA (sqin/sqft)...? '.160536' sqin/sqft*
  Q) Below-grade R-VALUE (F-sqft/Btuh)........? '14.0784' F-sqft/Btuh *
  R) Floor R-VALUE (F-sqft/Btuh)..............? '2' F-sqft/Btuh*
  S) Eqv Floor RESIST' outs'd (F-sqft/Btuh)...? '36' F-sqft/Btuh*
  Y) < DELETE this Component >...
  Z) < Changes COMPLETED >...
```

** This input is for the heated base case house only.

Appendix E

CIRA OUTPUT FOR THE BASE CASE HOUSE

The output is for the unheated basement case for the city of Windsor.

```
CIRA--------------Computerized Instrumented Residential Audit--------------

                             Related data...

                     Occupants' Name: FAMILY

                          House Name: Podury

                     House Area(sqft): 1000

                   House Volume(cuft): 8000

                                City: DETROIT

                        Latitude(deg): 42

                       Altitude(feet): 633

                         Azimuth(deg): 0

        Solar storage factor(unitless): .22

             Thermal time constant(hr): 8.54843

                     Free heat(Btu/hr): 2507.36

                      Moisture(lb/day): 3.79999

      Building Load Coefficient(Btu/hr/F): Yearly / Heating / Cooling:
          222.263                         238.023                      211.006

         Conduction Coefficient(Btu/hr/F): Total / Ceiling / Floor:
          148.942                         37.3266                      .232269

                 Leakage area(sqin): Total / Ceiling / Floor:
          76.5921                         42.6251                      6.57998

         North/East/South/West/Horizontal December Solar access(%):
       100          60.0001          55.2081          60.0001          100

           North/East/South/West/Horizontal June Solar access(%):
       100          79.9999          37.5555          79.9999          100

         North/East/South/West/Horizontal heating season SA(sqft):
     21.8424        20.9058          21.6584          20.9056          8.89603

         North/East/South/West/Horizontal cooling season SA(sqft):
     21.8424        20.9058          21.6584          20.9058          6.89603

Heating day/night thermostats(degF)   Cooling day/night thermostats(degF):
          70                    70                    70                    70

Yearly Electric Cons.(kWh)/Cost($) -- Yearly other Fuel Cons.(MBtu)/Cost($):
       11478.6             436.186             42.1007             242.079


CIRA--------------Computerized Instrumented Residential Audit--------------
```

```
CIRA--------------Computerized Instrumented Residential Audit----------

                  a       b       c       d       e       f       g       h
              Dload   Nload   DayOn   NitOn   SpEgy   Infil   T gas   Telec

      Jan:      2.8     3.6    13.9    18.2    12.0    0.61     120     975
      Feb:      2.0     3.2    10.9    18.0     9.7    0.65      97     881   :
      Mar:      0.6     2.2     3.4    10.9     5.3    0.56      53     975
      Apr:     -1.2    -0.0     0.0     0.0     0.0    0.53       0     943   :
      May:     -1.9    -0.1     0.0     0.0     0.0    0.48       0     975   :
      Jun:     -3.3    -0.5     0.0     0.0     0.0    0.38       0     943   :
      Jul:     -3.9    -0.7     0.0     0.0     0.0    0.36       0     975   :
      Aug:     -3.5    -0.8     0.0     0.0     0.0    0.37       0     975   :
      Sep:     -2.3    -0.4     0.0     0.0     0.0    0.36       0     943   :
      Oct:     -0.8    -0.0     0.0     0.0     0.0    0.45       0     975   :
      Nov:      0.9     1.8     4.7     9.2     5.0    0.55      50     943   :
      Dec:      2.3     3.1    11.7    15.4    10.1    0.62     101     975   :

 yr(sum):      -8.2    11.3    44.8    71.7    42.1    5.91     421   11479   :
yr(mean):      -0.7     0.9     3.7     6.0     3.5    0.49      35     957   :


                 a = A) - Dload - Daytime sensible load (MBtu)
                 b = B) - Nload - Nighttime sensible load (MBtu)
                 c = C) - DayOn - Daytime HVAC On-time (%)
                 d = D) - NitOn - Nighttime HVAC On-time (%)
                 e = E) - SpEgy - Space cond. energy use (MBtu)
                 f = F) - Infil - Infiltration (ac/hr)
                 g = G) - T gas - Overall gas use (therm)
                 h = H) - Telec - Overall elec use (kWh)
```

```
CIRA--------------Computerized Instrumented Residential Audit---------

                 a       b       c       d       e       f       g       h
               Telec   DewPt   Sgain   Rloss   VBDDy   Spce$   Gas $   Elec$

      Jan:       975    20.7    0.80    0.47    1115    68.8    68.8      37
      Feb:       881    18.3    1.15    0.44     882    55.8    55.8      33
      Mar:       975    29.5    1.65    0.49     500    30.6    30.6      37
      Apr:       943    39.4    2.12    0.46    -217     0.0     0.0      36
      May:       975    46.5    2.46    0.44    -377     0.0     0.0      37
      Jun:       943    58.8    2.60    0.37    -767     0.0     0.0      36
      Jul:       975    61.8    2.78    0.37    -944     0.0     0.0      37
      Aug:       975    64.1    2.39    0.35    -879     0.0     0.0      37
      Sep:       943    58.6    1.79    0.37    -552     0.0     0.0      36
      Oct:       975    46.2    1.34    0.44    -161     0.0     0.0      37
      Nov:       943    35.5    0.80    0.45     477    28.9    28.9      36
      Dec:       975    26.1    0.60    0.47     932    57.9    57.9      37

  yr(sum):     11479   505.6   20.49    5.12       9   242.1   242.1     436
 yr(mean):       957    42.1    1.71    0.43       1    20.2    20.2      36


                      a = H) - Telec - Overall elec use (kWh)
                      b = I) - DewPt - Indoor Dew Point (deg F)
                      c = J) - Sgain - Solar gain (MBtu)
                      d = K) - Rloss - Sky radiation loss (MBtu)
                      e = L) - VBDDy - Var. Base Degree Days (F-day)
                      f = M) - Spce$ - Space cond. cost ($)
                      g = N) - Gas $ - Overall gas cost ($)
                      h = O) - Elec$ - Overall elec cost ($)
```

Appendix F

CIRA OUTPUT FOR THE BASE CASE HOUSE: OTTAWA

The output is for the unheated basement case for the city of Ottawa.

```
CIRA--------------Computerized Instrumented Residential Audit--------------

                          Related data...

                   Occupants' Name: FAMILY

                        House Name: Podury

                   House Area(sqft): 1000

                 House Volume(cuft): 8000

                              City: OTTAWA

                     Latitude(deg): 45.3

                    Altitude(feet): 413

                      Azimuth(deg): 0

      Solar storage factor(unitless): .22

          Thermal time constant(hr): 9.17793

                    Free heat(Btu/hr): 2507.36

                    Moisture(lb/day): 3.79999

     Building Load Coefficient(Btu/hr/F): Yearly / Heating / Cooling:
         207.018                       219.15                   190.034

        Conduction Coefficient(Btu/hr/F): Total / Ceiling / Floor:
         133.972                       31.4588                  .232254

               Leakage area(sqin): Total / Ceiling / Floor:
         76.5921                       42.6251                  6.57998

        North/East/South/West/Horizontal December Solar access(%):
       100          60.0001          54.7476        60.0001          100

          North/East/South/West/Horizontal June Solar access(%):
       100          79.9999          37.017         79.9999          100

        North/East/South/West/Horizontal heating season SA(sqft):
     21.4663        20.6656          21.309         20.6656          7.93609

        North/East/South/West/Horizontal cooling season SA(sqft):
     21.4663        20.6656          21.309         20.6656          7.93609

Heating day/night thermostats(degF)   Cooling day/night thermostats(degF):
        70                 70                   70                    70

Yearly Electric Cons.(kWh)/Cost($) -- Yearly other Fuel Cons.(MBtu)/Cost($):
      11478.6          436.186              59.3084               341.023

CIRA--------------Computerized Instrumented Residential Audit--------------
```

```
CIRA---------------Computerized Instrumented Residential Audit----------


                 a       b       c       d       e       f       g       h
               Dload   Nload   DayOn   NitOn   SpEgy   Infil   T gas   Telec

       Jan:     3.6     4.8    18.0    23.7    15.5    0.62     155     975
       Feb:     2.5     3.8    14.0    21.0    11.8    0.66     118     981
       Mar:     1.3     2.9     6.6    14.6     7.9    0.60      79     975
       Apr:     0.2     1.4     1.3     7.1     3.0    0.55      30     943
       May:    -1.1    -0.1     0.0     0.0     0.0    0.47       0     975
       Jun:    -2.5    -0.3     0.0     0.0     0.0    0.41       0     943
       Jul:    -2.5    -0.7     0.0     0.0     0.0    0.31       0     975
       Aug:    -2.5    -0.5     0.0     0.0     0.0    0.30       0     975
       Sep:    -1.1    -0.2     0.0     0.0     0.0    0.37       0     943
       Oct:     0.2     0.7     1.0     3.9     1.8    0.42      18     975
       Nov:     1.2     1.7     6.3     9.2     5.6    0.50      56     943
       Dec:     3.3     4.1    16.5    20.4    13.7    0.62     137     975

   yr(sum):     2.5    17.6    63.6    99.9    59.3    5.84     593   11479
  yr(mean):     0.2     1.5     5.3     8.3     4.9    0.49      49     957


                      a = A) - Dload - Daytime sensible load (MBtu)
                      b = B) - Nload - Nighttime sensible load (MBtu)
                      c = C) - DayOn - Daytime HVAC On-time (%)
                      d = D) - NitOn - Nighttime HVAC On-time (%)
                      e = E) - SpEgy - Space cond. energy use (MBtu)
                      f = F) - Infil - Infiltration (ac/hr)
                      g = G) - T gas - Overall gas use (therm)
                      h = H) - Telec - Overall elec use (kWh)
```

```
CIRA--------------Computerized Instrumented Residential Audit---------

                a       b       c       d       e       f       g       h
              Telec   DewPt   Sgain   Rloss   VBDDy   Spce$   Gas $   Elec$

     Jan:       975     6.8    1.01    0.43    1534    89.1    89.1      37
     Feb:       881    13.9    1.21    0.39    1135    67.7    67.7      33
     Mar:       975    22.9    1.78    0.44     780    45.4    45.4      37
     Apr:       943    32.4    1.81    0.44     299    17.4    17.4      36
     May:       975    43.2    1.70    0.43    -246     0.0     0.0      37
     Jun:       943    52.7    2.06    0.39    -598     0.0     0.0      36
     Jul:       975    61.8    1.70    0.34    -740     0.0     0.0      37
     Aug:       975    59.2    1.80    0.36    -708     0.0     0.0      37
     Sep:       943    53.1    1.24    0.37    -280     0.0     0.0      36
     Oct:       975    44.5    1.11    0.41     188    10.4    10.4      37
     Nov:       943    34.8    0.62    0.41     584    32.0    32.0      36
     Dec:       975    13.2    0.79    0.44    1353    79.0    79.0      37

 yr(sum):     11479   438.3   16.84    4.85    3302   341.0   341.0     436
 yr(mean):      957    36.5    1.40    0.40     275    28.4    28.4      36


             a = H) - Telec - Overall elec use (kWh)
             b = I) - DewPt - Indoor Dew Point (deg F)
             c = J) - Sgain - Solar gain (MBtu)
             d = K) - Rloss - Sky radiation loss (MBtu)
             e = L) - VBDDy - Var. Base Degree Days (F-day)
             f = M) - Spce$ - Space cond. cost ($)
             g = N) - Gas $ - Overall gas cost ($)
             h = O) - Elec$ - Overall elec cost ($)
```

Appendix G

CIRA OUTPUT FOR HOUSE WITH A HEATED BASEMENT

The following output is for the heated basement case for the city of Windsor.

```
                              Related data...

                         Occupants' Name: FAMILY

                              House Name: Podury

                        House.Area(sqft): 2000

                      House Volume(cuft): 8000

                                    City: DETROIT

                           Latitude(deg): 42

                          Altitude(feet): 633

                            Azimuth(deg): 0

           Solar storage factor(unitless): .22

                Thermal time constant(hr): 12.1031

                        Free heat(Btu/hr): 2507.36

                        Moisture(lb/day): 3.79999

          Building Load Coefficient(Btu/hr/F): Yearly / Heating / Cooling:
            313.969                       328.805                        293.196

             Conduction Coefficient(Btu/hr/F): Total / Ceiling / Floor:
            227.395                       37.3266                        78.6856

                    Leakage area(sqin): Total / Ceiling / Floor:
            89.3535                       42.6251                        19.3414

             North/East/South/West/Horizontal December Solar access(%):
         100             60.0001          55.2081          60.0001          100

               North/East/South/West/Horizontal June Solar access(%):
         100             79.9999          37.5555          79.9999          100

             North/East/South/West/Horizontal heating season SA(sqft):
       21.8424           20.9058          21.6584          20.9058          8.69603

             North/East/South/West/Horizontal cooling season SA(sqft):
       21.8424           20.9058          21.6584          20.9058          8.69603

 Heating day/night thermostats(degF)   Cooling day/night thermostats(degF):
           70                      70                      70                     70

 Yearly Electric Cons.(kWh)/Cost($) -- Yearly other Fuel Cons.(MBtu)/Cost($):
         11478.6                436.186               55.5829                319.601


 CIRA--------------Computerized Instrumented Residential Audit------------
```

```
CIRA--------------Computerized Instrumented Residential Audit---------


                  a       b       c       d       e       f       g       h
               Dload   Nload   DayOn   NitOn   SpEgy   Infil   T gas   Telec

       Jan:      4.5     5.5    16.9    20.5    13.9    0.75     139     975
       Feb:      3.4     4.9    14.1    20.2    11.5    0.79     115     881
       Mar:      1.5     3.5     5.8    13.2     7.1    0.68      71     975
       Apr:      0.2     1.5     1.0     6.1     2.6    0.62      26     943
       May:     -1.5    -0.1     0.0     0.0     0.0    0.56       0     975
       Jun:     -3.3    -0.5     0.0     0.0     0.0    0.43       0     943
       Jul:     -4.0    -0.8     0.0     0.0     0.0    0.40       0     975
       Aug:     -3.6    -0.8     0.0     0.0     0.0    0.41       0     975
       Sep:     -2.2    -0.3     0.0     0.0     0.0    0.41       0     943
       Oct:      0.3     1.3     1.3     5.0     2.4    0.53      24     975
       Nov:      1.7     2.8     6.7    11.1     6.4    0.66      64     943
       Dec:      3.8     4.6    14.2    17.4    11.7    0.75     117     975

   yr(sum):      0.7    21.6    60.0    93.5    55.6    6.98     556   11479
  yr(mean):      0.1     1.8     5.0     7.8     4.6    0.58      46     957


                       a = A) - Dload - Daytime sensible load (MBtu)
                       b = B) - Nload - Nighttime sensible load (MBtu)
                       c = C) - DayOn - Daytime HVAC On-time (%)
                       d = D) - NitOn - Nighttime HVAC On-time (%)
                       e = E) - SpEgy - Space cond. energy use (MBtu)
                       f = F) - Infil - Infiltration (ac/hr)
                       g = G) - T gas - Overall gas use (therm)
                       h = H) - Telec - Overall elec use (kWh)
```

```
CIRA--------------Computerized Instrumented Residential Audit----------

                 a       b       c       d       e       f       g       h
               Telec   DewPt   Sgain   Rloss   VBDDy   Spce$   Gas $   Elec$

       Jan:      975    19.9    0.80    0.47    1227    80.1    80.1      37   :
       Feb:      881    17.5    1.15    0.44     999    66.3    66.3      33   :
       Mar:      975    28.9    1.65    0.49     634    40.6    40.6      37   :
       Apr:      943    39.1    2.12    0.46     226    14.7    14.7      36   :
       May:      975    46.2    2.46    0.44    -205     0.0     0.0      37   :
       Jun:      943    58.6    2.60    0.37    -539     0.0     0.0      36   :
       Jul:      975    61.6    2.78    0.37    -690     0.0     0.0      37   :
       Aug:      975    63.9    2.39    0.35    -648     0.0     0.0      37   :
       Sep:      943    58.3    1.79    0.37    -373     0.0     0.0      36   :
       Oct:      975    45.8    1.34    0.44     215    13.5    13.5      37   :
       Nov:      943    35.1    0.80    0.45     580    36.9    36.9      36   :
       Dec:      975    25.5    0.60    0.47    1032    67.4    67.4      37   :

  yr(sum):     11479   500.5   20.49    5.12    2456   319.6   319.6     436   :
 yr(mean):       957    41.7    1.71    0.43     205    26.6    26.6      36   :


                 a = H) - Telec - Overall elec use (kWh)
                 b = I) - DewPt - Indoor Dew Point (deg F)
                 c = J) - Sgain - Solar gain (MBtu)
                 d = K) - Rloss - Sky radiation loss (MBtu)
                 e = L) - VBDDy - Var. Base Degree Days (F-day)
                 f = M) - Spce$ - Space cond. cost ($)
                 g = N) - Gas $ - Overall gas cost ($)
                 h = O) - Elec$ - Overall elec cost ($)
```

VITA AUCTORIS

1961	Born on July 5 in Pondicherry, India.
1977	Completed All-India Higher Secondary Examination Course from Kendriya Vidyalaya, Central School, Pondicherry, India.
1982	B Eng. (Honours) (MECHANICAL), from Regional Engineering College, University of Madras, Tiruchirapalli, India.
1984	Currently a candidate for the Degree of Master of Applied Science from the Department of Mechanical Engineering, University of Windsor, Windsor, Ontario, CANADA.