A METHODOLOGY FOR INVESTIGATING THE ENERGY USE OF PROPOSED RESIDENTIAL DEVELOPMENT

By

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ABSTRACT

This thesis tests the feasibility of developing a methodology for investigating the energy use of proposed residential development. Recent experiences with energy impact assessment are examined, methods for predicting energy use and energy savings are identified, and applicable principles from environmental impact assessment are examined. It is determined that current energy evaluation procedures could be improved, based upon principles for developing assessment methodologies that have arisen from environmental impact assessment experience. Predictive methods are deemed necessary for forecasting the energy use of the proposed development and for predicting energy savings and greater energy efficiencies that could be achieved through various measures. An examination of predictive methods and energy saving measures indicates that not all supposed energy saving methods can be substantiated.

A new methodology is proposed which incorporates the principles of accuracy and objectivity and the need to quantify energy use and energy savings before changes to the development are required. This test reveals that, although there are currently limitations to data, the methodology could highlight means for potential energy savings, as well as illustrate some changes to conventional development practices that could lead to changes in spatial relationships and built form.

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I. INTRODUCTION

Settlement patterns in North America were formed in an era when lifestyle was not dependent upon non-renewable sources of energy. As gas and oil became a predominant factor in the continent's economy, and technology developed based upon an inexpensive and abundant energy supply, complex urban systems evolved. These systems continue to rely upon the availability of fuel at a relatively low cost. A fuel shortage or a substantial increase in price could significantly alter conventional development patterns and urban systems.

An altered energy situation has already begun to create changes in attitudes toward automobile-oriented development, particularly in parts of the U.S. that have experienced gasoline shortages. That particular scenario is only one symptom of the larger problem, which is the reliance of our society and economy upon limited, non-renewable energy sources.

One means of ensuring that future development is energy efficient is to investigate the energy consumption of residential development proposals, early in the planning process. Energy impact assessments are required for all new development in parts of the U.S. but have not yet been adopted for use in Canada. The State of California has incorporated energy efficiency considerations into its environmental assessment process. While the Province of Ontario has a firmly established environmental assessment process for all Provincial, Municipal and other designated developments, it has not included energy investigation as part of that process. The Province is responsible for ensuring an adequate supply of energy to its residents. The means of assessing the energy efficiency of residential development could be investigated as one part of a larger program to meet this responsibility. This thesis will examine the feasibility of developing a methodology for investigating the energy use of residential development. This chapter will discuss further the value of an energy use investigation procedure and introduce the topic of energy and energy efficiency.

A primary reason that an energy use investigation methodology may be useful is to identify means of reducing energy consumption in housing. This identification will highlight the features that could be responsible for development pattern changes and will also suggest a mechanism for preventing unnecessary energy consumption, and increasing energy efficiency. Energy efficiency and reduced energy consumption are two different concepts, but both apply to an investigation of residential energy use. Energy efficiency refers to the ratio of energy output to energy input, and is used when describing energy converters, while reduced consumption refers to lowering the need for energy inputs. Reducing energy demand and improving energy efficiency where energy is converted, can be considered in residential developments, in addition to substituting non-renewable forms of energy with renewable forms.

Energy use has not been a major factor in residential development decisions until recently, because it had always been abundant and relatively inexpensive. Settlement patterns and built forms have developed upon a foundation of a constant and inexpensive energy supply. The desire to reduce energy consumption could mean, however, that energy will become a more significant factor in influencing the shape of our physical environment and spatial relationships. There are many processes which result in a change to spatial form, and if control over physical development is desirable, it is important to understand these processes. An understanding of how energy may influence residential form could be achieved through the development of an energy use investigation methodology. This methodology could help determine which energy-related factors could bring about a change to conventional development forms, i.e., those that were established when energy was not a concern. Other similarly important reasons exist for developing an energy use investigation methodology, and these will be discussed in more depth, but the geographical application is relevant because of the extent to which a changed energy situation could affect human geography.

The current housing development situation is such that most residential construction takes place with little regard for the amount of energy that will be used. The energy consumption of a completed development in a cool climate can be unnecessarily high and many opportunities for conservation are often not considered.

Energy use is not an important consideration in regulating building construction in most places. Building construction has been regulated traditionally only to ensure the health and safety of occupants, and minimum standards are set to which builders must comply. These standards are often prescriptive, listing construction details which must be contained within the building. A small number of jurisdictions[1] have included minimum energy performance standards to be met by new buildings, but ~~this type~~ of regulation is as yet uncommon.

[1] Davis California; Portland, Oregon

Many regulations require walls and ceilings of residential dwellings to meet a minimum level of thermal resistance, and require double glazed windows. These requirements ensure that a certain amount of insulation is provided. However, they are usually not high standards and constitute only two of many conservation measures that could be addressed in building codes. Building construction standards to improve the energy efficiency of houses and other buildings have been recommended by various sources[2], but higher standards are rarely adopted as regulations.

Without regulation, there is little incentive for builders to change construction practices or to add features to a home to improve its energy efficiency. Extra features could increase the selling price of a home and it could become less marketable, as improved energy efficiency is generally not yet seen by buyers as a desirable feature worth the extra capital cost.[3] As a result, many homes are built to standards that do not maximize energy efficiency. (While this is true of most parts of North America, Ontario examples will be used throughout the thesis as illustrations.)

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[2] National Research Council of Canada. Measures for Energy Conservation in New Buildings, 1978, Ottawa.
Report of the Royal Commission on Electric Power Planning. Volume 5 Economic Considerations in the Planning of Electric Power in Ontario. pp. 121-124, 1980, RCEPP.

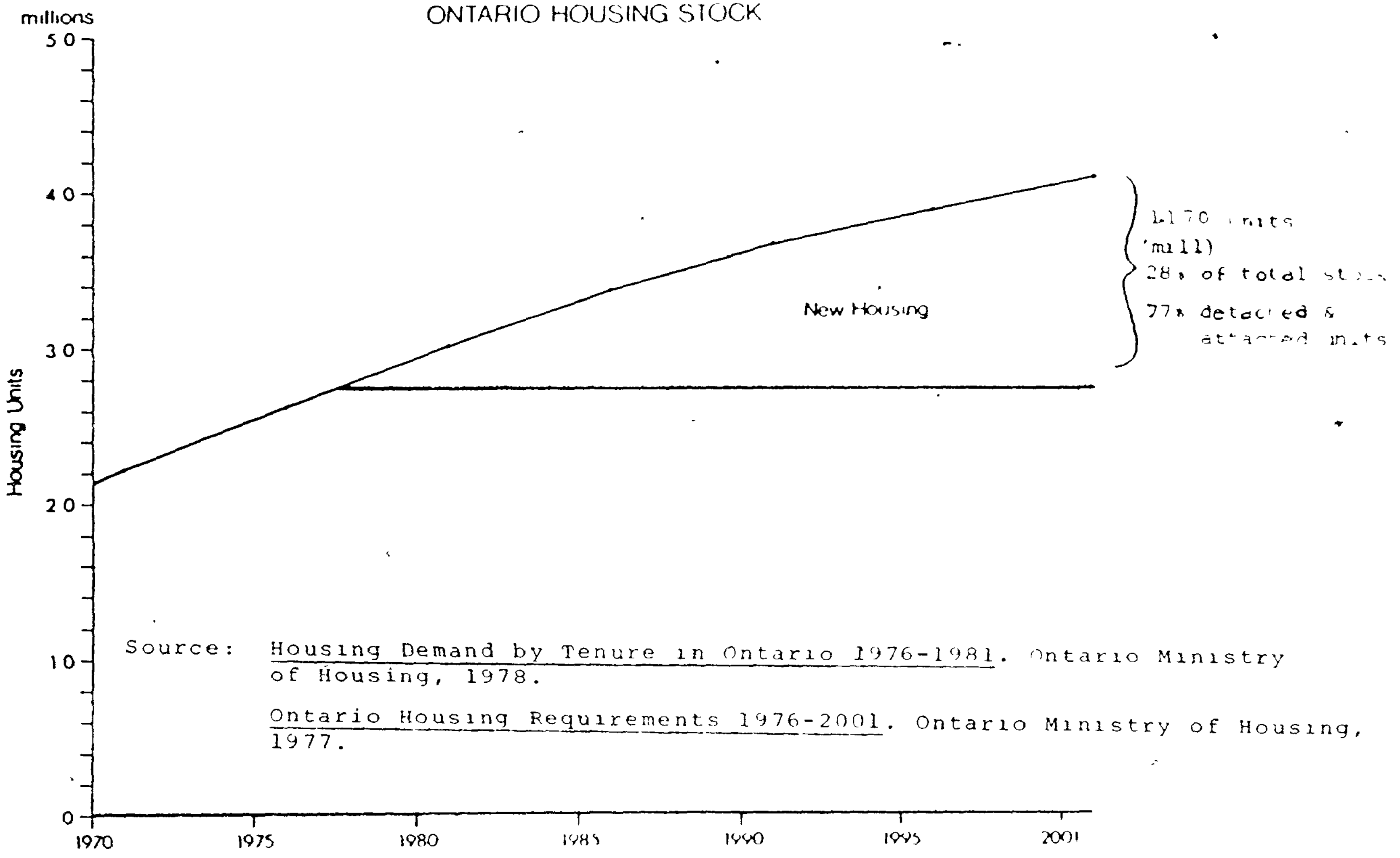
[3] Private communication from Erik Campbell-Smith, former president of the Housing and Urban Development Association of Canada

Figure 1 illustrates that while the majority of homes that will exist by the end of the century are already built in Ontario, construction will continue to occur, though at a declining rate. This suggests that any efforts aimed towards reducing residential energy consumption should first concentrate on existing housing.It is important, however, that the energy consumption of new housing be addressed for a number of reasons. As illustrated in Figure 1, new housing (that which will be built between 1980 and 2000) will comprise 28% of all housing in Ontario. If homes continue to be constructed as they are currently, that entire segment of housing will be consuming more energy than necessary.

In contrast to existing housing, measures taken to improve the energy efficiency of new buildings are far simpler to undertake. It is easier for a builder to incorporate features during initial construction rather than to add features to an existing home. By including energy consumption as a criterion for development in the initial design stages, there is greater scope for improvements for energy efficiency. Design details can be manipulated at this stage to optimize both the building envelope and its surrounding environment in terms of energy efficiency. This flexibility is not present to nearly the same extent in existing housing

Figure 1

ONTARIO HOUSING STOCK



Source: *Housing Demand by Tenure in Ontario 1976-1981*. Ontario Ministry of Housing, 1978.

Ontario Housing Requirements 1976-2001. Ontario Ministry of Housing, 1977.

Finally, improving the energy efficiency of new housing can be economically rational as it reduces home operating costs. Depending upon the type and extent of changes made in design and construction, capital cost could either decrease (due to narrower roads, driveways, sidewalks) or increase (due to extra insulation), but operating costs should always be lower in a more energy-efficient house.

In summary, there are a number of reasons for investigating residential energy use. Approximately one million new housing units will be constructed in Ontario in the next 20 years. There has been little move by the construction industry to build more energy-efficient homes, and regulations do not address energy consumption in a comprehensive manner. Therefore, energy is probably not being used efficiently. Opportunities for reducing both waste and home operating costs are often being overlooked or ignored. Advantage is not being taken of measures that could more easily be incorporated into new homes than into existing housing stock. An investigation into the expected energy consumption of proposed developments and into means of reducing consumption could be the first step toward more energy-efficient housing, and could result in significant changes to traditional housing development.

Energy use analysis is not the only means, however, of improving energy efficiency in housing. The market could be left to determine the type of housing to be built (the "do nothing" option). Builders, architects, and planners could be trained to improve house construction design and planning. Incentives could be provided or regulations could be established.

The simplest approach would be to do nothing, and wait for various market forces to create a demand for more energy-efficient homes. Expertise in energy-efficient design and construction might then emerge to meet the demand. Reliance upon the free market system rules out the need for a government role, but is not fully effective because of the time lag before demand is created. It could be speculated that demand for homes that require less energy could increase as the cost of energy increases, but the future of energy costs is an unknown factor, making it difficult to forecast demand. All housing developments constructed before that demand existed would then be constructed less efficiently than possible.

Energy use analysis could be utilized as a mandatory disclosure tool. As such, it would be a form of regulation. Unlike the first approach, however, time lag would not be a problem, as regulations can come into force at a specified time, beyond which all housing construction would take energy consumption into consideration. Regulation would thus be more effective in influencing the greatest amount of construction, than would waiting for market forces to bring about a change to development practices.

Education of those people involved with the housing development industry is another alternate method of incorporating energy considerations into housing projects. The argument has been advanced that providing educational programs for development professionals would preclude the need for regulation, as the professions would automatically adopt new practices.[4] In order for this approach to be as effective as regulation, all professions would have to undergo retraining, and to accomplish this, retraining would likely have to be mandatory. A method of monitoring and penalization may then be necessary to ensure compliance with the new practices. This approach would likely be complex, and would become essentially another form of regulation.

The provision of incentives and disincentives could also be used to influence energy consumption in new housing. Negative and positive incentives could take many forms including withholding

[4] Grant P. Thompson, Building to Save Energy: Legal and Regulatory Approaches (Cambridge, Mass.: Ballinger, 1980), p. 66

municipal services from inefficient forms of housing, placing a surcharge on household energy consumption beyond a certain level as disincentives, or removing taxes from building materials that contribute to improved energy efficiency, and allowing energy bills below a certain level to be tax deductible, as positive incentives.

These are just a few examples, but they indicate that the use of incentives can result in a complex set of administrative procedures, and can be costly to governments. Costs are also involved with an investigation of energy use as it would require a capital cost outlay by the developer which likely would in turn be passed on to the homebuyer. The cost would be minimized, however, by dividing it among each house in the entire development, and it is unlikely that these costs would exceed the energy saving benefits resulting from the investigation.

An energy use investigation regulation could be integrated into existing development approval processes so that given an established procedure for carrying out and reviewing the assessment, administrative procedures would be no more complex than without this new feature. Requiring a statement of expected energy use may not have the immediate effect of altering housing design and construction practices, but it would combine regulation and persuasion in an attempt to speed up market forces towards energy efficiency. As energy consumption is not yet considered by developers and home buyers to be an important concern in housing, this approach could be more acceptable than more stringent regulation or disincentives.

In summary, housing is currently being developed with little concern for its energy consumption. This results in energy waste, as there are many opportunities for improving the energy efficiency of housing by fairly simple means. There are several possible approaches to encouraging the production of more energy-efficient housing; each has strengths and weaknesses. Requiring an investigation of energy use could be an approach that is easily administered and acceptable to those involved.

This thesis will construct a method for investigating residential energy use by examining the energy inputs to housing developments, determining means of predicting energy consumption, and then by testing the method on an actual housing subdivision.

II. REVIEW OF THE LITERATURE

Because energy consumption in buildings has only recently been widely examined, the body of literature on investigating energy use in housing is not extensive. There have been attempts in the U.S. to formulate an investigation procedure, which will be discussed further as a basis for refinement and testing. In addition to reviewing these attempts, the development of a comprehensive means of investigating energy use in housing necessitates consideration of literature pertaining to the measurement of energy use in housing, and the various ways to reduce energy consumption in housing developments. The measurement of energy use in a standard housing development is necessary to provide a baseline for comparison against possible conservation measures. This information will provide the major components for the investigation methodology.

A related field of literature from which valuable experience may be drawn is that of environmental impact assessment. Although it involves a multi-variate decision-making process as opposed to evaluating simply one factor affecting the development project, the environmental impact assessment experience has generated some principles for dealing with development impact that may be applicable to an investigation of energy use.

This section will review the three major bodies of related literature defined above, 1) experience with energy use assessment, 2) methods of predicting housing energy use and means of reduction, and 3) the cognate field of environmental impact assessment. The information gained from this review will contribute to the development of the energy investigation methodology, which will then be fully described and tested.

Past Experience With Energy Use Assessment

The State of California has begun to include an assessment of energy use in its environmental review process. According to Christopher Rabenda[5], California has been the only State to

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[5] Christopher Rabenda, "Assessing the Energy Impact of Proposed Development: A Study of the California Experience," 1979, Ontario Ministry of Energy library

pursue vigorously the implementation of energy impact assessment although nine other states[6] and the Federal Council on Environmental Quality have acknowledged the need for taking energy effects into account in the review process.

A 1975 amendment to the California Environmental Quality Act of 1970 (CEQA), requires a discussion of energy impacts as part of environmental review reports which are prepared for all major developments. As a result, different approaches to assessing energy impacts have been taken in that State. Rabenda investigated the experiences of various California municipalities with this new planning element and found that energy assessments were being conducted with varying levels of commitment and sophistication.

The State issued suggested guidelines for the content of energy impact assessments, but not all municipalities have chosen to follow them. The State suggested in the guidelines that an energy impact assessement should essentially use the framework that was established in the 1970 National Environmental Policy Act (NEPA) for the preparation of environmental impact statements. That legislation requires that statements include information on:

> "1) The environmental impact of the proposed action,

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[6] Delaware, Maryland, Massachusetts, Michigan, Montana, New Jersey, New York, Washington, and Wisconsin. Rabenda, 1979

ii) any adverse environmental effects which cannot be avoided should the proposal be implemented,
iii) alternatives to the proposed action,
iv) the relationship between local short term uses of man's environment and the maintenance and enhancement of long term productivity and
v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented"[7].

The California energy impact guidelines list nine related categories of investigation. The first three categories are 1) project description - energy requirements for construction, maintenance and operation of the project, 2) environmental setting - energy supply and use in the region and 3) environmental impact - effect on local and regional energy supplies. All three categories relate to component i) of NEPA; environmental impact.

The guidelines also suggest in the remaining six categories, 1) a discussion of alternatives, in terms of reducing wasteful energy consumption; 2) mitigation measures, including conservation measures; 3) reduction of peak demand and use of alternative fuels; and 4) unavoidable adverse effects. The final categories are: 5) short term gain versus long term impacts, or life cycle energy, and 6) the energy consumed by growth induced by the project.

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[7] Quoted in John G. Rau and David C. Wooten, Environmental Impact Analysis Handbook, (California: McGraw-Hill, 1980), p.1-2

These categories cover the range of energy impacts that could result from a project, but they do not offer means for undertaking the types of analysis that they suggest. Because the analytical techniques are not defined and because strict adherence to the guidelines is not mandatory, municipalities have developed different approaches to evaluating energy use.

Contra Costa County has developed one of the most comprehensive procedures for evaluating the energy use of both building projects and planning policies.[8] The procedure generally follows NEPA's environmental assessment requirement in that it analyzes long term commitment, adverse impacts, possible alternatives, and mitigation measures.

The first major part of the process involves gathering data on energy use. The County has identified six categories of energy-related features of building projects including 1) the regional context of the project - location of required services and facilities; 2) site conditions - vegetation, topography; 3) climate - wind speed, solar days; 4) description of project - floor area, uses; 5) local planning standards related to energy use - zoning; and 6) energy sources - amount and type. This first

[8] Rabenda, 1979

step provides a description of the project and its energy consumption. The second phase of the project computes the long term (20 year) commitment to energy of the project and determines the amount of energy used through the construction period and that used for the subsequent operation and maintenance of the project.

The third and final step analyzes the energy efficiency of the project by using a checklist. The list identifies inefficiencies associated with the project under the six categories in step one and recommends mitigation measures. The energy assessment thus completed becomes one part of a larger environmental impact report.

Although the State guidelines and the Contra Costa County procedures have contributed to the advancement of knowledge in the investigation of energy use, there are shortcomings which should be avoided if an energy evaluation procedure is to have widespread use. Rabenda concludes in his report that the major reason for the ineffectiveness of energy impact assessment in California is the lack of information on how to undertake such an assessment. This shortcoming is evident in the above description of the two approaches.

Both outlines described the energy-related information that must be taken into consideration, but neither specify the techniques to be used for measuring the energy consumption associated with the various characteristics that have been listed. This is particularly evident in the State guidelines as they suggest investigating energy requirements of the project and the mitigation measures, yet do not offer concrete examples of how energy requirements are measured or what mitigation measures are effective. As a result, there is no base procedure by which projects will be analyzed across the State.

The Contra Costa County procedures take the State guidelines one step further by identifying the energy consuming components of building projects and establishing an energy efficiency checklist. Again, the means by which the energy consumption of each project is measured are not specified and the level of mitigation achieved by the recommended energy conservation measures is unknown.

The lack of these elements could result in inappropriate application of energy impact assessment. Different methods of analyzing energy use in developments could yield differing estimates, and using a subjective approach to recommending mitigation measures could result in costly and ineffective changes to a project. The development of the methodology must therefore specify energy measurement techniques and quantify the level of savings expected by mitigation measures.

In response to a perceived growing need for analytical tools to assess energy impacts Blair Folsom (1980) outlined a methodology which he believes provides the necessary techniques. This methodology is the only major attempt to date to identify the steps involved in energy impact analysis, and as such, will be discussed in detail. He states in Rau and Wooten's Environmental Impact Analysis Handbook (1980) that an energy analysis should answer the question "Why does it matter if this project consumes energy?",[9] and focusses his methodology on the implications of a project's energy consumption within a regional context. The structure recommended for the energy impact statement follows that of NEPA, as energy statements will in most cases in the U.S. be formulated as part of the environmental impact statement required by that Act.

A differentiation is made among energy consuming, producing and conserving projects but the recommended organization of the analysis is similar in each case. Housing developments are energy consuming projects and the framework for analysis is described as one which should include an inventory of energy flows into and out of the region created by the project. Following the inventory is a description of conservation measures employed by the project, a discussion of the energy supply and demand scenarios created, and a discussion of energy-related alternatives to the project.

[9] Rau & Wooten, 1980 p.5-3

The energy inventory for a consuming project, according to Folsom, should list the amount of energy required during the construction phase and the expected energy consumption for maintenance and operation of the project.

While sources of information for calculating energy use during construction are not provided, he does list methods for determining space heating energy requirements. The three methods he suggests are: computer programs, manual methods and gross energy use factors.

He goes on to explain that computer programs require very specific building design data and that all programs to date are not in the public domain. Simplified manual methods are described in the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) handbooks and while they too require specific data inputs, they are considered to be widely accepted and suited for small numbers of buildings. The least reliable source is energy usage factors, which are average energy consumption values for various types of buildings measured over time.

The description of energy conservation measures should include a quantification of the savings resulting from each measure, and should be incorporated into the energy inventory. This should then provide a figure for the expected energy consumption of the project, given the conservation measures, which should be used for determining impacts on supply/demand scenarios.

The third major step described by Folsom, after the energy inventory and the tabulating of conservation measures employed, is the discussion of energy supply and demand scenarios. According to Folsom the main reason for undertaking an energy assessment is to determine the changes that will be made by the project to supply/demand scenarios. He stresses the importance of defining a study area, that is, the geographical area whose energy flows will receive a significant impact as a result of the project;

> "A 'significant impact' is defined here as a projected change in any of the energy flows..... of more than one per cent of the existing or projected amount without the project. The number of scenarios to be presented depends upon the project's size. For example, a small project may affect a city's energy flow by less than one per cent, and in this case, one scenario - the city, may be sufficient. However, a large project which changes the nation's energy flow by more than one per cent would require several levels - for example, the United States and specific states, counties, and cities".[10]

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[10] Rau & Wooten, 1980 p.5-37.

Folsom is saying throughout his methodology, in essence, that the key reason for an energy assessment is not to ensure that an energy consuming project uses energy in the most efficient manner possible, but to ensure that the project in question does not have an adverse effect on the availability of energy to the surrounding region.

In carrying out the supply/demand section of the methodology, information is gathered on the energy consumption of the "study area", and the sources of supply. This data is compared to the expected energy consumption of the project, as defined in the energy inventory phase. If the projected energy consumption is less than one per cent of the study area consumption, then the project is deemed to have an insignificant impact. If the proportion is greater than one per cent, Folsom suggests that the proponent must demonstrate that the energy required is available, or that shortages can be mitigated.

He describes the major potential adverse impacts that must be mitigated as being power demand problems, energy demand problems, and economic problems. Power demand problems occur when energy facilities cannot meet the demand for energy, and are not necessarily the result of depleted energy sources. The consuming project with a significant energy impact must therefore ensure that energy facilities are in place to meet demand, in order to mitigate the impact.

Energy demand problems are related to the long term depletion of the resource base. The forecasted energy consumption of the project throughout its lifetime must be compared to the forecasted depletion date of the energy source in the region to determine impacts.

Economic problems are related to price changes due to power and energy demand fluctuations, government regulations and solvency of the energy industry. The effects of energy consuming projects on economic problems, and the possible mitigation measures are not described by Folsom.

The final phase of the energy impact assessment methodology is a discussion of the alternatives, both general and energy-related, that are not employed in the project. The purpose of this discussion is to demonstrate that the project will be constructed in the most desirable manner. The two main energy alternatives that could be considered are the use of different fuels, and conservation features. Folsom states that the discussion should centre only on reasonable alternatives that could have been considered, and suitable reasons must be provided for their absence.

While the methodology outlined by Folsom for assessing energy impacts, as described above, is seemingly more thorough than that developed by the State of California or Contra Costa County, his emphasis is markedly different. As stated earlier, Folsom believes that an energy impact assessment should focus not upon the appropriateness of the amount of energy consumed by a project, but upon the relevance of that energy consumption in a wider context. In the true sense of the word "impact", which means to influence or affect, Folsom's interpretation of the requirements of an energy impact assessment could be considered appropriate. However, in the practical application of an approach, the California methods, which are, strictly speaking, analyses of the energy-related features of a project for the purposes of assessing or evaluating the energy consumption, rather than an impact assessment, may be more appropriate, for reasons which will be discussed further.

The inventory of energy use and listing of energy conservation measures are common to all three methodologies described, and is a logical starting point for a study of energy use. An inventory provides the basic data necessary for evaluation. It is a description of that which is to be analyzed. The data sources listed by Folsom are applicable only to the U.S., except for his suggested method of heat loss calculations which can be applied in most geographical contexts. In order to carry out an Ontario-based case study of a methodology, Canadian data sources must be identified.

The description of energy conservation measures employed in the project, which is the next step suggested in Folsom's methodology, would simply be an informational item, as the energy savings should already have been accounted for in the inventory. However, providing this information would be helpful in presenting a more complete picture of the project.

The departure in approaches comes with Folsom's third step, the discussion of the energy supply and demand scenarios. Following his logic that a project has no significant energy impact if it produces a change of no more than one per cent of the energy flow of the study area, it would seem that in that case, there would be no rational reason for improving the energy efficiency of the project wherever possible. The next step, discussion of alternatives, seeks to ensure that the project is developed in an energy-efficient manner, but this step is not a logical consequence of the previous step.

Another shortcoming of Folsom's approach is its poor applicability to the majority of development projects that would be evaluated in terms of energy use. An initial problem would arise in gathering meaningful data on energy supply and demand of a defined study area. Because of the varying supply and distribution networks of the major energy suppliers it would not be possible to define a single study area for comparing to the project's energy consumption, except at the level of the entire state or province. While hydro-electric power is distributed by municipal utilities in many areas, oil, natural gas, and gasoline are not distributed according to municipal boundaries. This would make comparable data-gathering difficult, and more importantly, make it difficult to identify any adverse impacts of a project.

Power demand problems that might occur as the result of a development project are most easily identified, as this is simply a matter of determining whether or not hydro capacity exists, or gas or oil pipelines are in place or can be extended (in this sense, including this analysis as part of an energy investigation will provide energy suppliers with more accurate information than they would normally have, upon which to base their needs forecasts). Yet power demand problems would seem remote in the case of many small projects such as housing developments, if this methodology was applied, as the widespanning supply and distribution networks of energy suppliers would be compared to the needs of many minor energy users. In the case of a large energy consuming project such as a major industrial development, an energy impact might be felt on a state or provincial scale, but for most housing developments such an impact would not likely occur.

Energy demand problems due to resource depletion would not be indicated by comparing forecasted project consumption with the depletion date of the study area. At any level lower than that of the state or province, energy would rarely be produced within study area boundaries. The energy supply would more often be imported, in which case the depletion of that source must be used in comparison.

The reliability of energy forecasting is an additional uncertainty, because of fluctuation in demand over time, and uncertainties regarding the recovery of new sources.

The third problem, that of energy price changes, is not due to the increased energy consumption resulting from new development, as Folsom himself states.

It would appear from this review of attempts to define a method for investigating energy consumption in new development that a combination of the approaches could be most suitable for application to new residential development. The first step, after describing the project, would consist of an inventory of forecasted energy consumption from construction through to operating energy use This inventory should then be compared with any standards or regulations on energy consumption that exist, to ensure conformity. The next step should consist of analyzing alternative ways to develop the project that would result in energy savings, and finally, mitigation measures arising from this step would be prescribed. Long term commitment to resource use would not be discussed as it could be assumed that the development will consume energy as long as it exists. However, the availability of energy supply should be discussed in the first step under regional context, to ensure that the energy distribution network was in place or would not result in energy shortages due to the need to construct new distribution facilities.

Folsom's method may be applicable to large energy consuming projects such as industries, where actual energy impacts may occur, but for the majority of housing developments these more simple procedures could ensure that construction takes place in the most efficient manner. The revised procedure indicates that the NEPA format may not be the most appropriate for this purpose.

Given this revised procedure, there is a need for techniques to measure energy consumption, to identify alternatives and to quantify the benefits to be derived from mitigation measures. As with the State of California and the Contra Costa County guidelines, the procedures will only be useful if measurement techniques exist.

Thomas Dickert, in his comparison of environmental impact assessment methods,[11] has recognized this need and the problems associated with it. He classified environmental impact assessments into the three analytic functions of identification, prediction, and evaluation. Identification methods specify the possible range of impacts, and evaluation methods identify impacts of alternatives and tradeoffs, while predictive methods define the quantity of impact of a project, according to Dickert. It is these predictive methods which must now be defined in order to carry out an investigation of energy use.

Dickert goes on to say that most assessment guidelines and methods do not address the question of predictive methods, and that both NEPA and CEQA merely make explicit the need to apply science in decision-making but go no further in offering methods. He states that the discussion and use of predictive methods in assessments is limited to current scientific knowledge and that this is a fundamental problem for providing factual data in impact statements.

For the purposes of applying the energy investigation procedure, it will thus be necessary to identify, wherever possible, existing methods for predicting quantities of energy consumption.

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[11] Thomas Dickert, <u>Environmental Impact Assessment: Guidelines and Commentary</u>, (California: The Regents of the University of California, 1974) p.127

The next section of the literature review will identify and analyse these predictive methods, which will then be used in testing the procedure.

Methods of Predicting Energy Use

The energy inventory phase requires that all forms of energy use in the housing development be identified and consumption forecasted. According to the various assessment methods, energy is used in housing developments for:

1. Construction - energy is embodied in construction materials, and is used by construction equipment.
2. Space Heating
3. Water Heating
4. Lighting - street lighting and room lighting.
5. Appliances
6. Maintenance - snow removal, garbage collection etc.
7. Transportation

A potential problem lies in identifying where to draw the line with respect to energy flows associated with the project. Space heating and lighting are obvious energy users of the project but following the course of the energy chain indicates that energy is also used in, for example, extracting, processing and shipping the raw materials that are used to manufacture the furnace that provides space heating, manufacturing the furnace, and transporting the manufactured furnace to the site. This chain of events could be traced for every component of the project. Similarly, regional travel patterns could be affected and travel distances increased as a result of particular characteristics of the development. At this stage in the development of the energy assessment methodologies consumption data at that level of detail is limited. However, as techniques are developed to provide this data, it will be important to disentangle and tabulate only those energy flows that form a significant (possibly greater than 5 per cent) portion of the project energy use. The significance could be dependent upon whether the component was a "one time" energy user (furnace) or an ongoing user (increased travel). The energy use of the component would be compared with the project's annual or lifetime energy use, respectively.

An important factor in calculating energy consumption is the efficiency of the energy supply system. The true energy consumption of any fuel type includes both the direct energy used by, for example, watching television for an hour, and the energy required to produce the electricity. Electrical generating stations are fuelled by a variety of sources such as oil, coal, uranium, and water and are generally only 30 per cent efficient, so the annual household electricity consumption figure must be divided by .30 to determine the net energy consumption. Similarly, gas fired furnaces are approximately 65 per cent efficient, (although more efficient furnaces are currently being developed), so the annual BTU requirement should be divided by .65 to find the total energy consumption for space heating.

The first form of energy used in a new housing development is embodied energy. Embodied energy refers to the energy inputs to construction i.e. the energy that is required in raw material, extraction and processing, transport of component to manufacturer, all manufacturing processing and transferring of the unit from the supplier to the job site and finally to its incorporation into building. Emphasis on energy use in buildings has, in the past, been on the operation of buildings, primarily because this was an obvious energy use, was easily measured, and simple methods existed for reduction. But a group of researchers at the University of Illinois have found that the energy use in the construction of new buildings was as much as 20 per cent of that used to operate the entire stock of building that existed in 1967 in the U.S.[12] and was 9 per cent of the total U.S. energy requirement in 1967.

Bruce M. Hannon et al. at the University of Illinois measured the amount of energy used in building construction through means of

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[12] Bruce M. Hannon et al. Energy Use for Building Construction (Urbana: University of Illinois, 1976) p.116

an input/output model. The model identified "direct" energy requirements of the construction industry in 1967, that is, energy used at the job site, and "indirect" energy requirements, which is that used in material. In addition, energy purchased per dollar of output by each economic sector selling to the building contractor (399-order sectors were identified) were determined, leading to an identification of energy cost per unit of various building materials. This research provides the basis for measuring total energy consumption in an area. Hannon was able to estimate the embodied energy per square foot in various types of residential buildings. With this information, the embodied energy requirements of buildings can be easily calculated. The shortcoming of the method is that Hannon's figures for a single family and -2 family residential are averages of embodied energy in these housing types across the U.S. Further development of this research could result in a predictive method adaptable to the characteristics of individual housing units, but until that time, the average figures offer the best method for estimating embodied energy use

In addition to embodied energy use in building construction similar figures are available for units of asphalt, clay and concrete, which are the basic components of roads, sewers, and sidewalks. This information can be used to determine energy consumption of the remaining construction components of the development.

The next major energy user in the development after the construction phase is space heating. There are a number of methods for predicting energy consumption for space heating. The standard method upon which most variations are based is a procedure developed by the American Society of Heating, Refrigerating, and Air Conditioning Engineers called the Degree Day Method. This method is used to determine both the peak amount of energy required by a house during the coldest temperatures and the annual amount of energy required.

The calculations basically consist of estimating heat loss from each room in a house while maintaining a desired indoor temperature. Heat loss occurs from both transmission and infiltration.

Transmission heat loss refers to the heat that escapes from inside the house to the outside through all surfaces such as walls, doors, and glass. Transmission losses can be determined by multiplying the exterior area of each surface by a corresponding coefficient of transmission or "U" value ("U" value is a measure of transmissivity of a material, or the extent ~~to which heat passes~~ through it), and by the design temperature difference, that is, the difference between the desired indoor temperature and the outdoor temperature. The peak heat loss (which heating systems are designed to provide for) is determined by adding the transmission heat loss and the infiltration losses.

The infiltration losses occur when cold air leaks into the house through small openings around windows and doors, or when windows and doors are left open. This cold air must be heated to the desired room temperature, which requires energy. Infiltration heat losses are determined by the following equation:

volume x air changes x infiltration heat loss factor x design temperature difference.

The volume of air to be heated is multiplied by the number of air changes per hour which is the number of times per hour that the total amount of air in a house is replaced by outside air. This change can vary from .2 to .4 per hour for newer houses (since 1976) to .5 to .8 to older houses.[13]

The infiltration heat loss factor is a constant value of .018. The outcome of these calculations is a figure defining the amount of energy required to heat a house during the coldest period of the year or the peak power requirements. This figure, when multiplied by the number of houses in an area defines the amount of power that a supply system must be able to provide to that area at any one time.

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[13] Informetrica Ltd. and Energy Research Group, Carleton University, Ontario Residential and Commercial Energy Demand Study (Toronto: Ontario Ministry of Energy, 1978) p.17

The traditional Degree Day Method of predicting annual energy consumption was to use the following equation:

$$\text{Fuel consumption} = \frac{\text{peak heat loss} \times \text{degree days} \times 24 \text{ hours}}{\text{design temperature difference} \times \text{furnace efficiency}}$$

This equation was based on an assumption by ASHRAE that:

> "On a long term average, solar and internal gains will offset heat loss when the mean daily outdoor temperature is 65F and that fuel consumption will be proportional to the difference between the mean daily temperature and 65F. In other words, on a day when the mean temperature is 20 deg F below 65F, twice as much fuel is consumed as on days when the mean temperature is 10 deg F below 65F".[14]

However, ASHRAE reports that since the time of this assumption, internal heat gains have increased due to better insulation and increased use of appliances. Therefore a modified degree day procedure for estimating annual heat losses has been developed to reflect the lower heat losses. The new equation includes correction factors based on emprirical data for actual residential energy consumption[15]:

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[14] American Society of Heating, Refrigerating and Air Conditioning Engineers, <u>1980 Systems</u> (New York: ASHRAE, 1980) p.43.9

[15] ibid.

Fuel consumption =

$$\frac{\text{peak heat loss} \times \text{degree days} \times 24 \text{ hours}}{\text{design temperature difference} \times N \times \text{furnace efficiency}} \times C_D$$

Where N = correction factor for increased load efficiency, part load performance, conservation devices (0.55)

C_D = correction factor for heating effects vs. degree days (.60 for areas with 4000-7000 degree days)

The ASHRAE procedure was recommended by Folsom to be used in the inventory of energy consumption, and is generally the most widely accepted method for determining energy requirements for space heating. There are computer programs for calculating energy consumption in buildings, but these are, to date, privately owned models.

According to Sizemore *et al*. (1979) computer programs "vary widely in ability to provide accurate results for a particular situation" and "the program logic is frequently hidden ... resulting in possible misapplication of the program".[16]

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[16] M. Sizemore *et al*., *Energy Planning for Buildings*, (U.S.A.: American Institute of Architects, 1979) p.22

It should be noted that large amounts of data relating to climatic conditions and building characteristics are required by any method of calculating heating energy requirements. The extent to which this need hampers the energy evaluation procedure must be assessed during the testing phase.

Water heating, lighting and appliances are the next energy users in housing development. They are grouped together because in each case, energy consumption can be predicted reasonably accurately from average consumption data, without the need to carry out analytical procedures. Average consumption data is available through surveys conducted by various agencies such as gas and electrical utilities, consumer groups and government bodies[17].

Surveys have been undertaken more in recent years in efforts to promote energy conservation and are easily obtainable. The information provided by this data is generalized over all houses in the study area but can be used with reasonable accuracy in the absence of more disaggregated data.

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[17] Examples of data availability are: Energy, Mines & Resources Canada, *100 Ways to Save Energy and Money in the Home* (1975) and Ontario Hydro "How You Use the Energy You Use" (1980)

Street lighting energy consumption data is also easily obtained from the authority responsible, which is usually the municipality. They can provide information concerning the standard distance between lights (to determine the number of street lights in a subdivision) the type of lighting used, and average annual energy consumption.

Transportation is the next major energy consumer related to housing developments. In order to assess accurately the actual transportation energy consumption attributable to a new development it would be necessary to identify the total number of trips generated by the subdivision for all purposes. Models are not available that can accurately predict trip generation at the necessary level of detail, but it is possible to predict the amount of transportation energy consumed within the boundaries of a subdivision. Upon reviewing the literature it is apparent that most transportation energy research focusses upon demand projection and engine efficiencies with little regard to the impact of land use configurations on transportation energy consumption. Subdivision layout conceivably can, however, influence travel patterns and therefore energy consumption.

A method has been developed by Middleton Associates[18] for predicting the transportation energy consumption of trips that originate within the subdivision and whose destination lies outside. The other two types of trips are: (1) Those with origin and destination within a subdivision; and (2) Origin outside the subdivision and destination within.[19]

With the exception of return trips whose origin was within the subdivision, these types of trips are not significant to the energy use of the subdivision. The commercial outlet, which could be the generator of internal automobile trips, is within easy walking distance of homes, and there are no community facilities that would attract trips from outside the subdivision.

The Middleton method measures transportation energy consumption by calculating the average distance between each home and the nearest arterial exist and multiplying this by the trips per year per household, and dividing by an automobile efficiency factor as in the following simplified equation:[20]

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[18] Middleton Associates, "Residential Site Design and Energy Conservation - Draft", (unpublished, Ontario Ministry of Energy Library, 1979)

[19] Middleton Associates, 1979

[20] To determine total internal transportation energy consumption it is necessary to multiply the distance between each home and the nearest arterial exist by 2, to account for return trips. This step is not included in Middleton's method.

Total annual gasoline consumption =

miles per trip x annual trips per household x number of households/miles per gallon

For calculating the distance to arterial roads, the subdivision is divided into a series of zones whose lengths are measured. The shortest route from each house to the nearest arterial road is then measured by adding the length of the zones.

The aggregate of these calculations provides the average distance between each house and the nearest arterial route. This figure is then multiplied by the average number of trips per year per household. Finally, this figure is divided by the average automobile fuel efficiency, to arrive at the number of gallons of gasoline consumed annually within the subdivision. This method requires specific transportation data to be available, but is fairly simple and would allow for a comparison of the energy consumption resulting from various street layouts.

Finally, energy is required to service and maintain the subdivision. Energy is used for garbage collection, snow removal, water supply and sewage treatment. Like water heating, lighting and appliances, the predictive methods for these forms of energy consumption could be derived from existing measurements and consumption is projected for the housing development based on these figures. Information pertaining to maintenance-related energy consumption should be available from the municipality responsible for maintenance. Municipalities have recently begun to undertake systematic energy accounting, whereby energy consumption audits of their operations are performed. This provides the information necessary on annual energy consumption for each operation.[21] This level of information must be disaggregated further to determine the related energy consumption for various densities and house types. There is no documented experience or procedure for identifying maintenance energy consumption at the subdivision scale, so this component of the inventory may have to be generalized and therefore less accurate than desirable. The importance of accuracy for this component will depend upon its significance to the energy consumption of the entire subdivision, which will be tested in the case study.

After the comparison of the energy inventory with any existing standards or regulations, the next major step in the proposed evaluation procedure is the identification and analysis of energy-saving alternatives. If the existing regulations are strict with respect to energy consumption or energy-conserving measures, then it may be adequate to investigate fewer alternatives.

[21] see, for example, <u>Network</u>, Vol. 1, No. 1, Oct. 1980, Association of Counties and Regions of Ontario

However, with the exception of a small number of municipalities it is accurate to assume that regulations of this nature are not common.[22]

The analysis of alternative, energy-saving approaches to developing a housing subdivision should include identifying the range of alternatives and assessing the appropriateness of each alternative to the housing development in question. The identification of energy-saving approaches requires keeping abreast of technological change and innovation.

Assessing the alternatives involves identifying the energy savings that could be achieved with each measure. This part of the energy investigation procedure is essential to ensuring that any changes to the development proposal that are required (which is likely to be the major result of the investigation procedure) are justified. The approaches to energy use investigation that were discussed earlier, with the exception of Folsom, do not discuss the importance of this element. They list a number of energy measures that should be considered, but do not explain whether or not they judge the "reasonableness" of measures before requiring them to be included in the development.

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[22] The National Research Council of Canada's Measures for Energy Conservation in New Buildings (1978) contains the most rigorous government standards to date in Canada, but these are not required by law.

As conservation measures could have adverse secondary impacts, such as increasing housing costs or reducing municipal services, some criteria should exist against which any proposed mitigation measures are assessed.

Folsom suggests that "the justification for choosing among these alternatives should be based on an analysis of the following factors: fuel availability, non-renewable resources, technology and equipment availability, certainty of supply, cost, other environmental factors (air pollution etc.)."[23] Fuel availability and technology and equipment availability are necessary criteria before the particular alternative can be considered as an option. Non-renewable resources should be taken into account in areas where they are in short supply. In such cases, the effect of the alternative on non-renewable energy sources should be considered.

Contrary to Folsom, however, it is not necessary as part of this methodology to calculate the cost of incorporating each energy saving measure as the purpose of the investigation is to identify how energy efficiency could be improved and where energy savings could be achieved in housing development, not to make the trade-off between dollar costs and energy savings

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[23] Rau and Wooten, 1980, p.5-52

The cost of incorporating some energy saving measures may be high, but the value of this methodology lies in its ability to present both the predicted energy consumption of the proposed development and the predicted energy savings given certain alternatives that are both technologically feasible and widely available. Dollar cost then becomes a separate issue. Environmental impacts of energy saving measures should be the subject of a separate assessment for the same reasons.

In order actually to apply the procedure using a case study, it is necessary here to review the possible alternatives to identify the range of choices that should be considered. The two major categories of choices are:

(1) The use of alternative fuels, and
(2) Energy conservation measures.

The use of alternative fuels should be considered in the context of the type of fuel available in an area, and whether or not renewable resources could be used. The different fuels or energy systems that could be considered include: natural gas, electricity, wood and solar energy. This list could be added to as new fuels or more efficient supply systems are developed.

Natural gas and electricity for space heating are currently the most common fuels to be considered for housing projects. The efficiency of the two forms of energy varies however. Electrical resistance heating is 100% efficient, and electric heat pumps are more than 100% efficient- while natural gas heating varies in efficiency from 65% to 80% depending upon the furnace. Top quality wood and wood furnaces can be 60 to 70% efficient.

In order to have a true account of the energy used in the development, it would be necessary to know the efficiency of the generation and distribution systems of the different types of energy used. This element is easily accounted for with electricity as the efficiency factor is known (30% for electricity supplied from power plants). It is more difficult to determine the system inefficiencies for other energy types such as natural gas and wood. It cannot be expected that an investigation of residential energy use will contribute to reducing these system deficiencies. However, the relative efficiencies to the extent that they are known, may become important criteria in evaluating the priority of alternatives.

A great amount of research is being conducted on the use of solar energy for home heating as a substitute for non-renewable fuels. Recent indications are that while active solar systems can be designed to provide 100% of space heating requirements at varying levels of efficiency in cold climates, problems in the mechanical system that require shutdowns are common, requiring an auxiliary heating system to be available.[24] Active solar systems have been proven to provide up to 70% of the energy required for domestic water heating, however.[25] Passive solar heating systems are capable of being designed to provide up to 50% of home heating requirements in cold climates.[26]

These alternative forms of energy should be considered in the development of the housing project by analyzing them in terms of the criteria listed earlier.

The second major category of alternatives is energy conservation measures. There are numerous housing-related energy conservation measures that have been investigated at both the early site planning level, and at the detailed housing design and construction level. Recent literature that summarizes past work will be reviewed here.

[24] Housing and Urban Development Association of Canada, Builders' Guide to Energy Efficiency in New Housing (Toronto: HUDAC, 1980) p.91, 92

[25] Thomas Lanczi, Assessment of Four Solar Domestic Hot Water Systems (Toronto: Ontario Ministry of Energy, 1980)

[26] Okins, Leipiciger, Cuplinskas, Kaminker & Associates Ltd., Residential Passive Solar Heating (Toronto: Ontario Ministry of Energy, 1980) p.2

The Contra Costa County evaluation checklist indicates that the regional context of the development is important and that sites easily accessible to services and facilities should be considered. The County also suggests avoiding the need for storm drainage sewers by allowing for natural drainage, minimizing construction energy input by reducing street widths and designing the street layout to minimize travel distances. The embodied energy savings of reducing servicing standards can be calculated, but it would be more difficult to determine the actual transportation energy savings from improving accessibility to services.

Middleton Associates (1979) have identified street layout as influencing gasoline energy consumption. Their analysis of three subdivision designs indicated that the street layouts resulted in a difference in energy consumption of 27%. The energy savings would be pertinent to both the residences and the energy consumed for municipal maintenance. This figure cannot be used as a guideline as the change in energy consumption attributable to street layout will be specific to each proposed development. In fact, the maximum energy savings that could be achieved by changing street layouts could only be determined by testing a large number of alternative layouts; a procedure that would lend itself to computer modelling, but not to manual calculations. Therefore, the energy savings cannot be readily measured.

G.O. Robinette's Landscape Planning for Energy Conservation (1977)[27], discusses the considerations that should be made in site planning and design to reduce space heating energy consumption. Initially, the location of the site should be one that has natural protection from winter winds to minimize infiltration. Where possible, building should take place on a south-facing slope to gain the most benefit from the sun for passive solar heating in winter. Other recommendations that he makes are:

- Use walls, fences and vegetation to reduce wind speed.
- Use natural and man made features as above to channel any cold air paths away from the house in winter and through the house in summer.
- In cold climates use dark colours on buildings to absorb the sun in winter.
- Roof should be flat or shallow pitched to hold the snow, which acts as an insulator.
- Use natural light wherever possible.

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[27] G.O. Robinette, Landscape Planning for Energy Conservation (Virginia: Environmental Design Press, 1977)

The *Builders' Guide to Energy Efficiency in New Housing* (1980) also recommends designing to take advantage of the sun and states that this should be done by placing the large glassed areas of the house on the south face and orienting streets in a predominantly east-west direction. In addition to using vegetation to reduce wind speed and infiltration, the *Builders' Guide* recommends minimizing the number of openings on north walls and placing non-living spaces there such as closets and washrooms.

The *Builders' Guide* goes on to discuss the most efficient form of building and states that because of lower surface area to volume ratios, two-storey houses use 14% less energy for space heating than bungalows with the same floor area, semis use 21% less, and row houses use 33% less energy. Therefore, the dwelling type to be used must be given careful consideration in planning a housing development.

In addition to site planning and dwelling factors, there are energy conserving features that can be added to the house during construction. The National Research Council of Canada's *Measures for Energy Conservation in New Buildings* recommends standards for thermal resistence for residential dwellings as follows: walls - R17, basements - R9, roofs/ceiling - R31.8. The savings resulting from extra insulation can be calculated using the Modified Degree Day Method.

Other conservation features include insulating hot water tanks and pipes and providing restricted flow fittings on faucets to minimize hot water usage. Fluorescent as opposed to incandescent lighting should be used, as fluorescent lighting is five times more efficient than incandescent. Finally, the Builders' Guide recommends providing heat pumps, and low voltage automatic setback thermostats to allow for easier regulation of space heating.

There are other means of reducing energy consumption and improving efficiencies such as constructing dome houses (least surface area to volume ratio) or underground homes, and providing greenhouses and vestibules. While the energy savings attributable to these measures can be predicted, there is no scientific method to determine if these types of measures would be acceptable to the project proponent or to the community. This energy use investigation methodology does not attempt to solve this problem, and thus investigates more conventional energy measures. The methodology does, however, provide a format for comparing the energy savings of various measures, while leaving the more subjective decision making to the evaluator, as the decision criteria could change from place to place.

The analysis of energy related-alternatives to the housing development requires the use of predictive methods, as did the energy inventory. The key factor in deciding which measures may be prescribed is the energy savings of each measure. The amount of energy savings of each measure will determine whether it is worthwhile to assess the measure with respect to fuel availability, certainty of supply, and technology and equipment availability. The review of recommended conservation measures indicates the large number of measures that have been promulgated by different sources and, in the case of Contra Costa County, have been incorporated into their development requirements. Yet of all the measures recommended, only those summarized in Table 1 have means of actually measuring the energy saved. It has not been proven in the literature that the energy characteristics of the other measures, though recommended by various sources, can be assessed.

Table 1

ENERGY CONSERVING OPTIONS

SPACE HEATING

- minimize transmission and infiltration heat losses
    - weatherstripping and caulking
    - increase insulation
    - minimize surface area to volume ratio
- minimize use of non-renewable fuel
    - passive or active solar heating
    - efficient furnaces
    - setback thermostats

LIGHTING

- fluorescent lights in houses
- high pressure sodium street lights

WATER HEATING

- efficient heaters
- solar water heaters
- restricted flow faucet fittings

EMBODIED ENERGY

- minimize use of asphalt and concrete
- allow for natural storm water drainage

In view of this shortcoming, it seems that to ensure a rational, scientifically-based recommendation of alternatives (in those cases where it is found necessary to prescribe alternatives) only those measures which have been proven to have greater energy efficiency, reduce energy consumption or which save non-renewable fuels where they are in short supply can be justifiably prescribed. The remaining conservation features could be suggested to the project proponent as indications of emerging research but should not be required in the development until their potential energy savings can be proven.

In summary, it has been illustrated that there are methods for measuring residential energy consumption and means for reducing consumption, and these predictive methods are an essential component of an energy investigation procedure.

Environmental Impact Assessment

The body of literature most closely associated with the development of an energy investigation methodology is that of environmental impact assessment. This literature has evolved largely due to the need to conform to environmental assessment legislation, and the methodologies that have developed are based upon existing planning evaluation methods such as the goals achievement matrix, planning balance sheet, and cost/benefit analysis. These tools were formulated as aids to the decision-making process within the context of multiple objectives, which environmental assessment involves. The two methodologies are not directly comparable, as energy use investigation involves only one environmental variable. However, a number of principles for developing an assessment methodology have arisen from environmental impact assessment which should be reviewed to determine if they are applicable in any way to energy use investigation.

Corwin, and Heffernan's (eds. 1975) Environmental Impact Assessment,[28] provides an environmental impact evaluation questionnaire that was formulated to determine the adequacy of impact reports, and lists some "overall considerations" that must be made. These considerations are broken down into the six categories of usefulness, scope, objectivity, thoroughness, nature of data, and summary. Under the first category, usefulness, the authors state that there should be enough information for any assessor to make an independent judgment on the impacts that are likely to occur. The scope of the impact statement should include regional as well as local impacts, and whether or not it requires

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[28] Ruthann Corwin and Patrick Heffernan, eds., Environmental Impact Assessment (San Francisco: Freeman, Cooper & Co., 1975)

a commitment to a larger project. To ensure objectivity, statements of fact should be easily verifiable, and under the category of thoroughness, information should be included about which methods have been used in the report and whether or not appropriate agencies have been consulted. The nature of the data should be such that it is sufficiently detailed to draw independent conclusions, and the summary should use reasonable rankings of the significance of the impacts.

Some of these considerations could be applicable in developing a methodology to investigate energy use. Although the methodology would not be used for determining energy "impacts" but for investigating the amount and type of energy used, the amount of information available in the energy investigation report should make clear to anyone the energy use of the proposal compared with alternatives.

With respect to the scope of the report, it has already been determined that an analysis of impacts of energy use on larger than the local area would not be meaningful. But the investigation should address whether or not the new development would require a commitment to build new energy supply facilities to determine if alternatives could avoid the need for this commitment.

Objectivity in an energy investigation report would come from describing the methods used to predict the energy use of the proposed energy development and the possible savings from alternatives, so that they can be easily verified. This provision also ensures thoroughness in the report.

Corwin and Heffernan's questionnaire suggests that detailed information be included in the report. This suggestion can easily be accommodated by including all of the energy use calculations, to allow for independent conclusions to be drawn, but is probably unnecessary if the methods used are well known and accepted. The summary of an energy investigation report would not rank impacts but would list energy consumption figures and could rank suggested mitigation measures based on the criteria to be used for evaluating alternatives.

Larry Canter (1977)[29] describes Smith's (1974) ten criteria for evaluating energy impact assessment methodologies, which includes some of the considerations discussed by Corwin and Heffernan, as well as some additional criteria. The additional criteria that could pertain to an energy investigation are that the state of the art should be utilized, and the evaluation criteria should be explicitly defined.

[29] Larry Canter, Environmental Impact Assessment (Toronto: McGraw-Hill, 1977)

The former criterion is particularly important in energy use evaluation. While the state of art of energy conservation technology is changing rapidly, the deployment and commercialization of the technology often lags behind. It will be important to distinguish the level of technology that is considered to be the state of the art when assessing alternatives and precribing mitigation measures. Also, the techniques for measuring the energy savings of possible alternatives may not be a part of the state of the art which indicates that the inclusion of these alternatives must be carefully weighed. The recommendation of explicitly defining evaluation criteria relates back to the earlier discussion of justifying alternatives to be considered, and reinforces this notion.

The idea of objectivity and the need for quantifying impact arises continually in environmental assessment literature. Other examples include Warner and Preston's 1973 study of 17 environmental impact assessment methods[30] and Greenberg and Hordon's (1974)[31] questioning of the adequacy of environmental impact statements, both of which emphasize these two criteria.

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[30] M.L. Warner and E.H. Preston, A Review of Environmental Protection Impact Assessment Methodologies (U.S.A.: Environmental Protection Agency: 1974)

[31] Greenberg & Hordon, "Environmental Impact Statements: Some Annoying Questions, JAIP 40(3) 164-175, 1974

Derek Coleman[32] suggests five major characteristics of importance in selecting an impact assessment technique. The first is adequacy, or the degree of precision in predicting impacts afforded by the technique, which is largely a function of the level of detail to which each criterion is analyzed. The second is replicability or the degree of objectivity so that consistent results are achieved by different individuals. The third characteristic is flexibility in terms of the different types of impacts that can be incorporated. The fourth is economy or the amount of information required to predict impacts. The final characteristic discussed by Coleman is understandability, that is, the ability to present information in a meaningful way to people of divergent backgrounds.

Accuracy and objectivity are highlighted again. It will be difficult to determine the degree of flexibility required in investigating residential energy use until a number of investigations have been completed. Economy does not appear to be an attribute of the energy use investigation methodology that has been outlined thus far, and the extent to which this is a

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[32] Derek J. Coleman, "Environmental Impact Assessment Methodologies: A Critical Review" in Environmental Impact Assessment in Canada: Processes and Approaches Proceedings of a Conference held at the Institute for Environmental Studies (Toronto: The University of Toronto, 1977)

detriment to the methodology will be tested. Understandability will be assessed after the investigation has been performed for the case study.

It is evident from this review of principles that have arisen from the field of environmental impact assessment, that some lessons could be applied to an energy investigation methodology. The importance of these principles will be determined in the case study.

The literature review that has been presented answers some key questions that had to be addressed before the energy investigation methodology could be developed. These questions were: What are the experiences to date with investigating residential energy use?; Are there reliable methods for predicting and evaluating housing-related energy use?; and What can be learned from associated fields of research?

The following chapters will draw from the review to suggest a methodology. The energy use investigation methodology, which is the subject of the next chapter, has been formulated through the literature review and critique. The methodology will be worked through on a sample housing development after which problems and refinements to the methodology will be identified, and conclusions drawn.

III. THE ENERGY USE INVESTIGATION METHODOLOGY

An energy investigation methodology for housing, based on past energy assessment experience, with knowledge of some predictive methods and principles, should include the following steps:

1. Description of the project
2. Energy inventory
3. Comparison of project with existing energy standards or regulations
4. Analysis of alternatives
5. Prescription of mitigation measures

The description of the project should describe the housing numbers and types, the location of the site in relation to employment, shopping, and recreation facilities. Although it was determined earlier that total transportation energy consumption could not be accurately predicted, this part of the description will provide more information about the proposed development. The site conditions, such as topography and vegetation should be listed. Climatic conditions such as temperature, wind speed, and sunshine hours should be provided, as well as the types of energy that will be used in the development.

The energy inventory phase is necessary to the methodology in order to identify opportunities for reducing consumption. It provides base data against which possible alternatives can be compared. The energy inventory should determine the amount of energy that will be used by each type identified in the first phase. To improve the level of objectivity of the investigation and to allow for verification, which was a recurring theme in the review of environmental assessment methodologies, it will be important to describe in detail the predictive methods used in the inventory. These methods are likely to change over time as new information becomes available but for the purpose of investigating residential energy use a number of methods or information sources were identified which should be used. They are summarized here as follows:

a) Embodied energy - Hannon et al. data

b) Space heating - ASHRAE Modified Degree Day Method

c) Lighting, Appliances, Water Heating - survey data where available; where unavailable, gross consumption data by utility service area could be collected.

d) Maintenance - municipal records

e) Transportation - Middleton "Zone" Method.

In order to determine if new energy supply facilities are required as a result of the development, it will be necessary to identify specifically the power requirements for natural gas and electricity uses. The important distinction between power and energy is that power is the rate at which energy is used in a certain period of time (demand) and energy is the total amount used (consumption). The demand must not exceed existing capacity or power shortages will occur. It is for this reason that the energy demand of appliances is included in the inventory, as appliances are not usually provided by the developer. Normally, planning regulations cannot influence the type of appliance used, therefore alternatives and mitigation measures for appliance energy use are not considered in the investigation procedure.

The comparison of the proposed development with existing energy standards or regulations involves checking the proposal against pertinent building code requirements and planning regulations for the area. Building code requirements are often minimum standards which must be met, but planning regulations can have some flexibility with respect to density, building design, and arrangement of lots. The development should take maximum advantage of opportunities within the framework of these regulations to incorporate energy conservation measures.

The analysis of alternatives should discuss alternative ways that the development could be carried out to improve its energy efficiency, by applying the considerations listed in Table 1 to the particular proposal. The energy savings that could accrue from each alternative measure or technique should be calculated to determine the difference in energy consumption to the housing development, had it been included. The method used for quantifying the potential energy savings should be described in detail to ensure objectivity and to allow for verification, as in the energy inventory phase.

Once the potential energy savings have been determined, each measure or technique should be further analysed with respect to the availability of the fuel type, and availability of technology and equipment. These are important considerations because although the energy savings of particular measures may be known, they cannot be considered as alternatives if the technology is only applicable in experimental cases or if equipment or fuel is not obtainable.

The preceding phases provide the information required to prescribe mitigation measures where necessary. The measures should be listed in order of priority, in deference to the principles suggested by environmental assessment experience, which involves listing the prescribed measures in order of their potential energy savings.

The energy use investigation procedure described above will only be successful if it is adopted by appropriate agencies, as a development review procedure. It is important in developing new procedures of this kind to determine how they could be utilized in the context of existing legislation and practices. The U.S. energy impact assessment procedure is included as part of the NEPA requirements for which a process was in place. Where the energy use investigation is a new feature, a means of ensuring its use should be identified.

The following chapter will test the feasibility of the energy use investigation methodology. The case study will determine the extent to which the methodology adheres to the principles drawn from environmental assessment experience and the validity of these principles, the difficulty of quantifying energy use and savings in terms of the complexity of the calculations and the availability of data, and the ease of incorporating the procedure into the planning process.

IV. PRACTICAL APPLICATION OF METHODOLOGY

The methodology will be tested by following through the procedures outlined for each phase for a selected housing development. An existing housing development has been chosen because information was readily available, but the methodology will be applied as though it were a proposed development.

1. Description of the project

a) Regional context - The proposed housing development is located in the Borough of Scarborough (see Figures 2 and 3) which is part of the Municipality of Metropolitan Toronto. The Borough offers a wide range of employment opportunities within its approximately ten mile radius and transit connections exist linking the area to further opportunities in the Metropolitan Toronto area. The subdivision is within four miles of a major regional shopping centre which offers department store-type merchandise catering to various income levels. A number of furniture and appliance warehouse outlets are located within one mile of the neighbourhood. A variety store is located within the subdivision offering convenience goods.

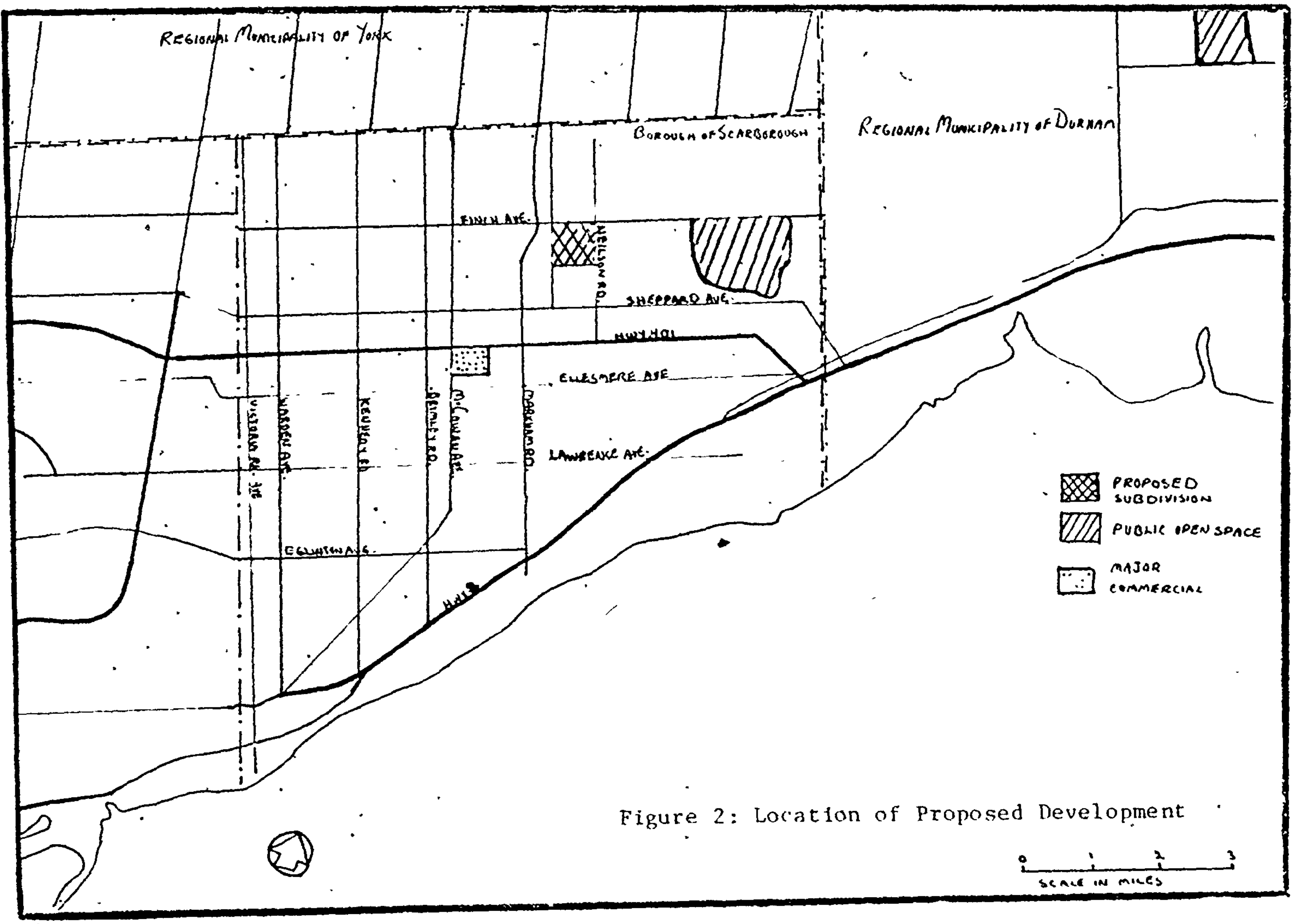

Figure 2: Location of Proposed Development

Figure 3

Plan of Subdivision

of Proposed Development

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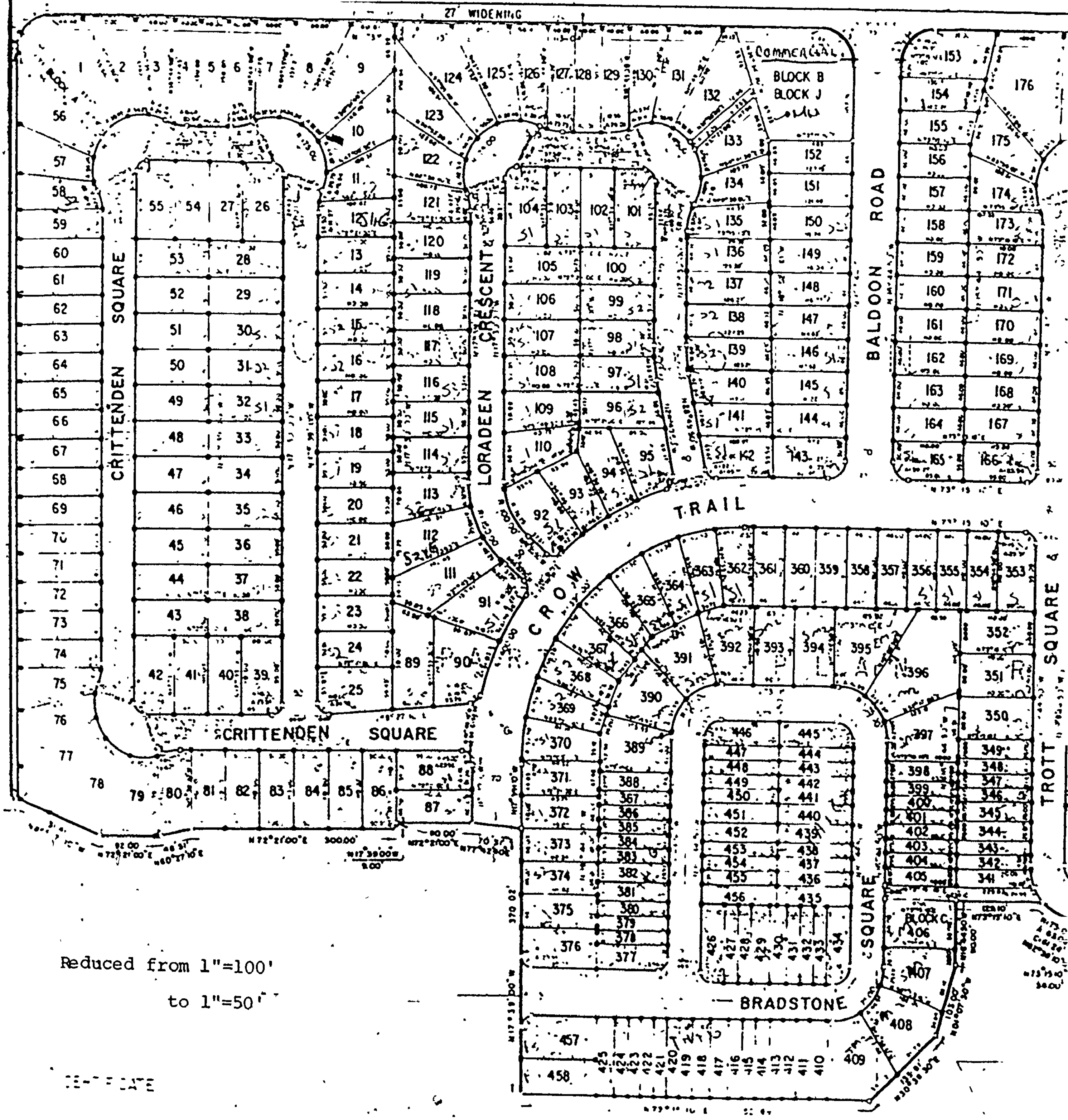

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CERTIFICATE

OWNER'S CERTIFICATE

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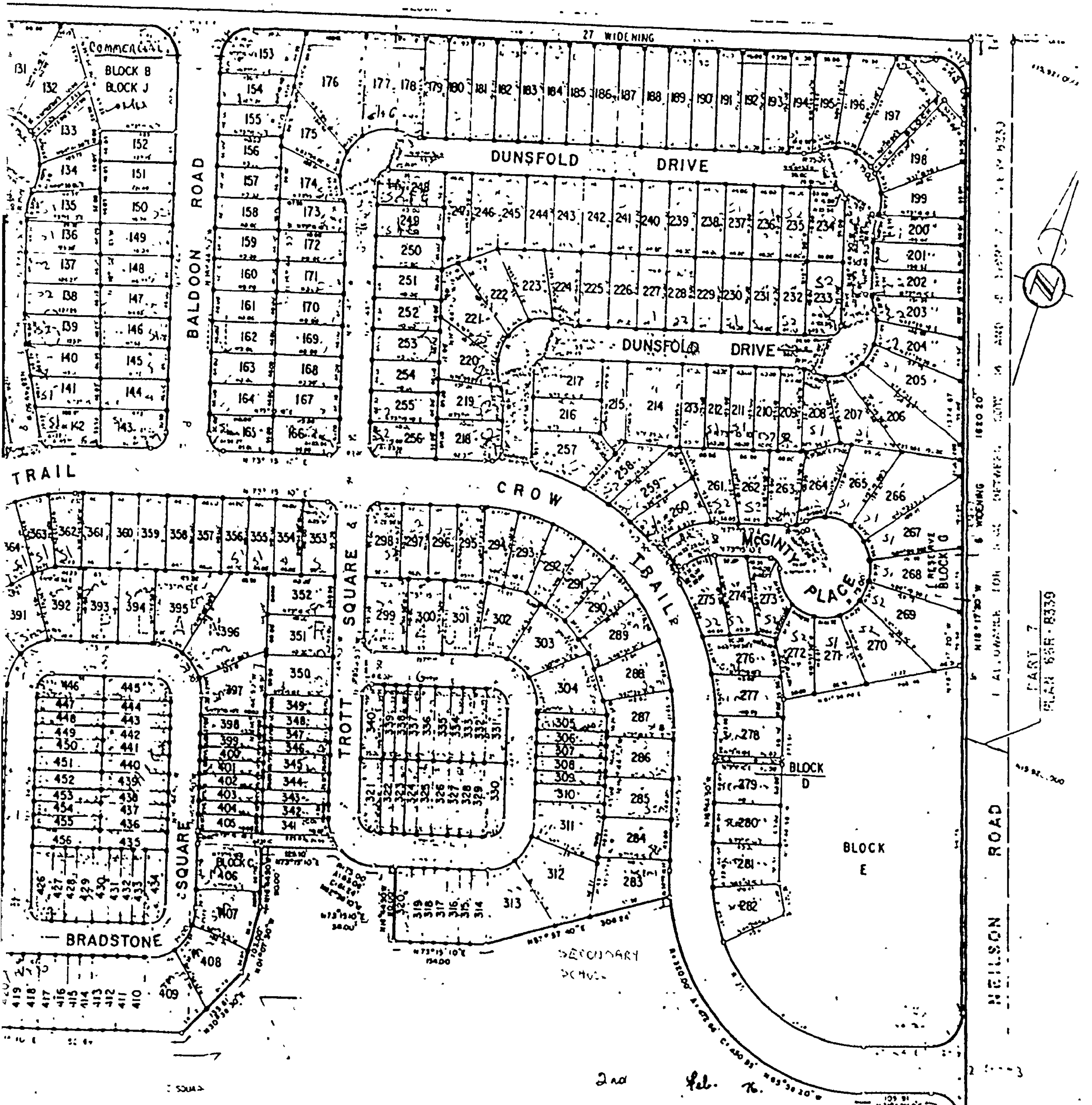

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A major zoo and winter sports facility is within five miles of the subdivision, and a large conservation area is within ten miles.

An elementary school is within short walking distance of the subdivision. A secondary school is located within the subdivision.

The subdivision is well served by local transit which also connects to the regional transit system for wider access.

b) Climate

Degree days - 6800 below 65°F annually

Bright sunshine - 2000 hours annually

Wind speed - 15 miles per hour winter average

Wind direction - predominantly northwest

c) Site

Households - 497

Housing type - 310 single detached (176 one-storey, 134 two-storey)

- 78 semi-detached, two-storey

- 109 row houses, two-storey

Landscaping - one tree per house, on boulevard

Roads - asphalt, 26 feet wide local roads, 32 feet collectors

Sidewalks - four feet wide, both sides of road

Storm drainage - storm sewers

Sewage disposal - municipal sanitary sewer system

d) Energy Type

Space heating - natural gas

Water heating - electricity

Lighting and appliances - electricity

Automobiles - gasoline

2. Energy Inventory

This phase of the evaluation will forecast the energy consumption of the proposed development by type to arrive at a total energy consumption figure for the development.

a) Embodied energy

Energy is embodied in the construction of both houses and infrastructure. Bruce Hannon et al. (1977) have estimated that the average amount of energy embodied in a single detached house is 702,047 Btu per square foot. The semi-detached and row units use 625,050 Btu per square foot. Using this information, the total amount of energy embodied in the housing units was calculated. Calculations are presented in the Appendix. Hannon also provides figures for the amount of energy embodied per unit in building materials for services. These energy consumption figures are used for calculating the energy embodied in the provision of services.

b) Space Heating

The energy required for space heating in the subdivision is forecast by using the ASHRAE Modified Degree Day Method. This method takes into account differences in dwelling type, size, and design, and has large data requirements.

The method requires that information be available for the exterior surface area of all units, construction materials and insulation values, air and ground temperatures, wind speed, air volume to be heated, air changes, annual heating degree days, and furnace efficiency. The calculations must be performed for each of the six dwelling types illustrated in Figures 4 to 9.

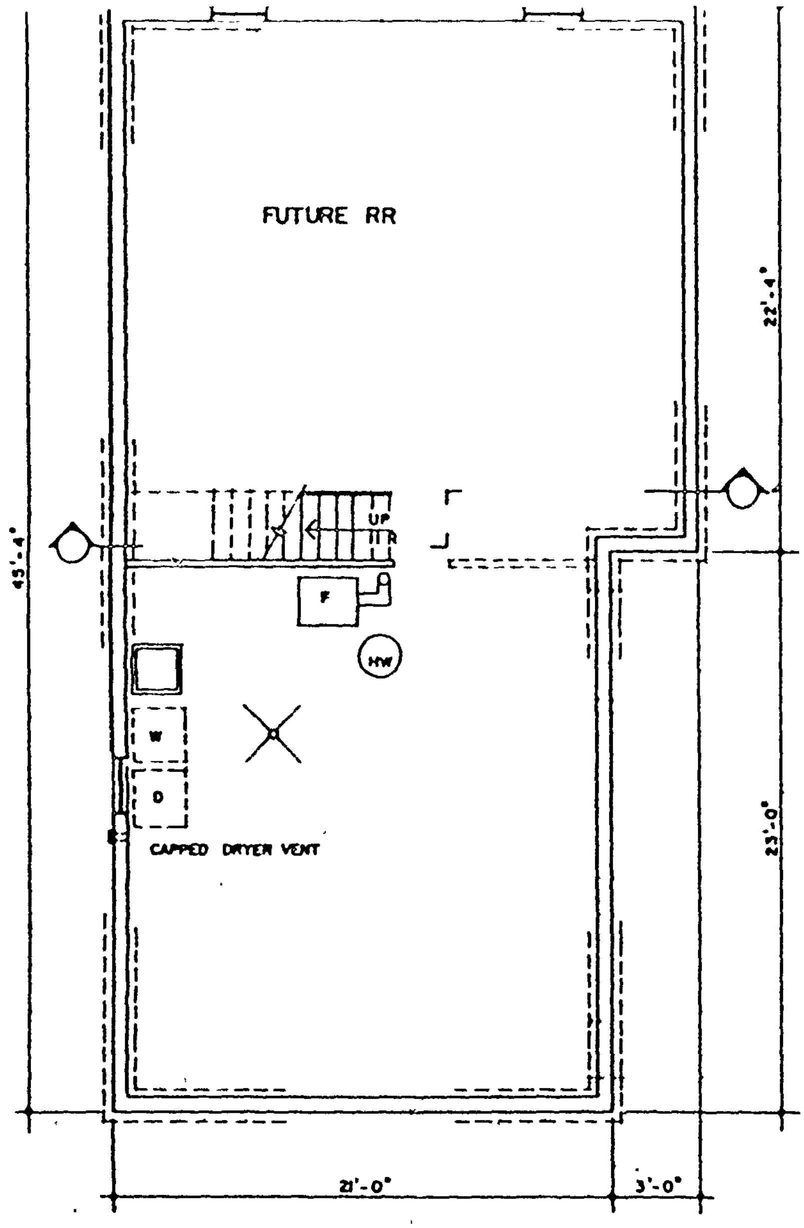
c) Lighting, Appliances, Water Heating.

Average consumption for indoor lighting, appliances and water heating in the subdivision was determined using data from a survey of electricity consumption that was prepared using information from Ontario Hydro[33] records.

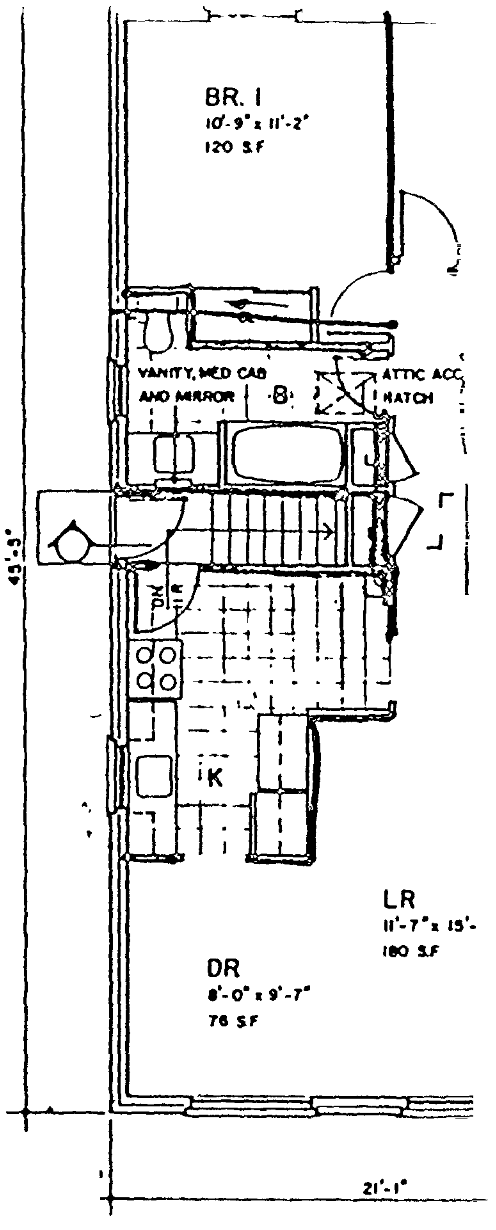
[33] Informetrica Ltd. and Carleton Energy Research Group, (1978)

Figure 4

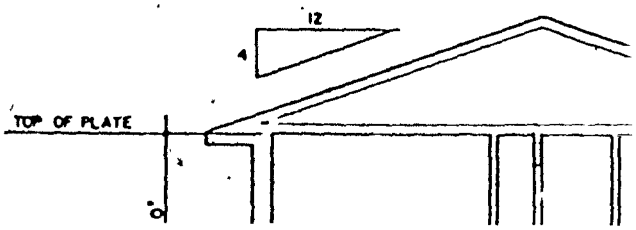
Dwelling Design 3.D.1. Type 2

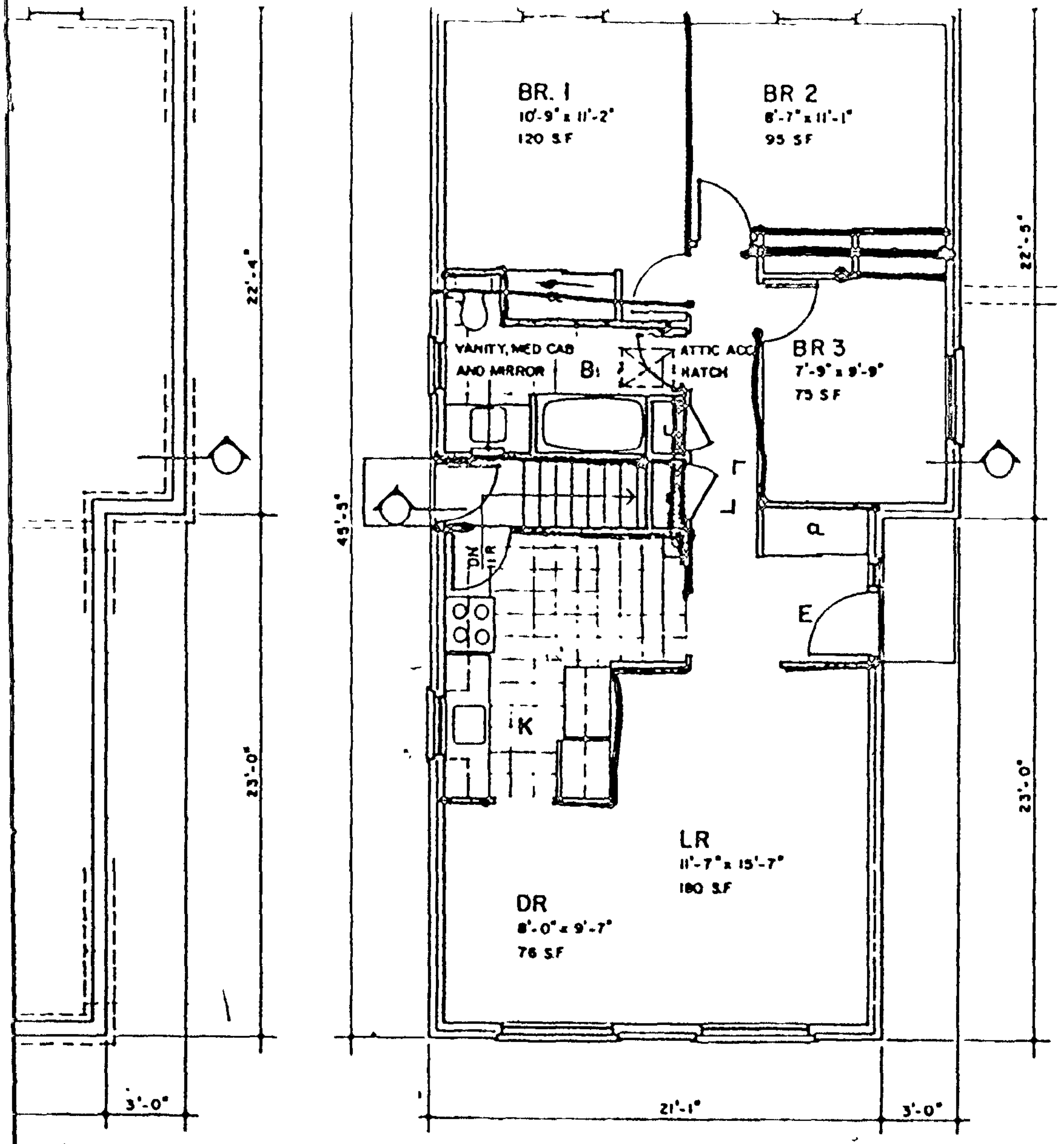


BASEMENT FLOOR PLAN



GROUND FLOOR PLAN





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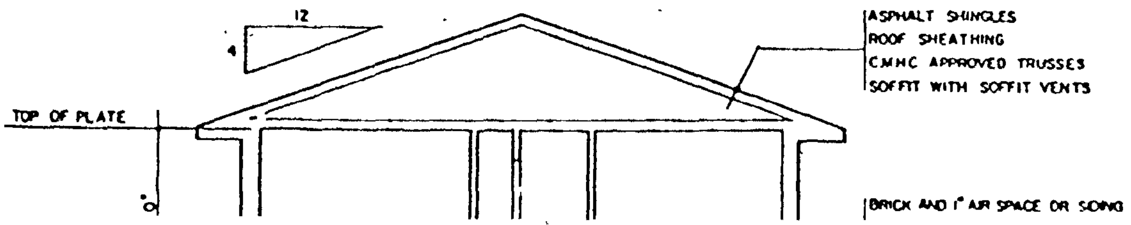

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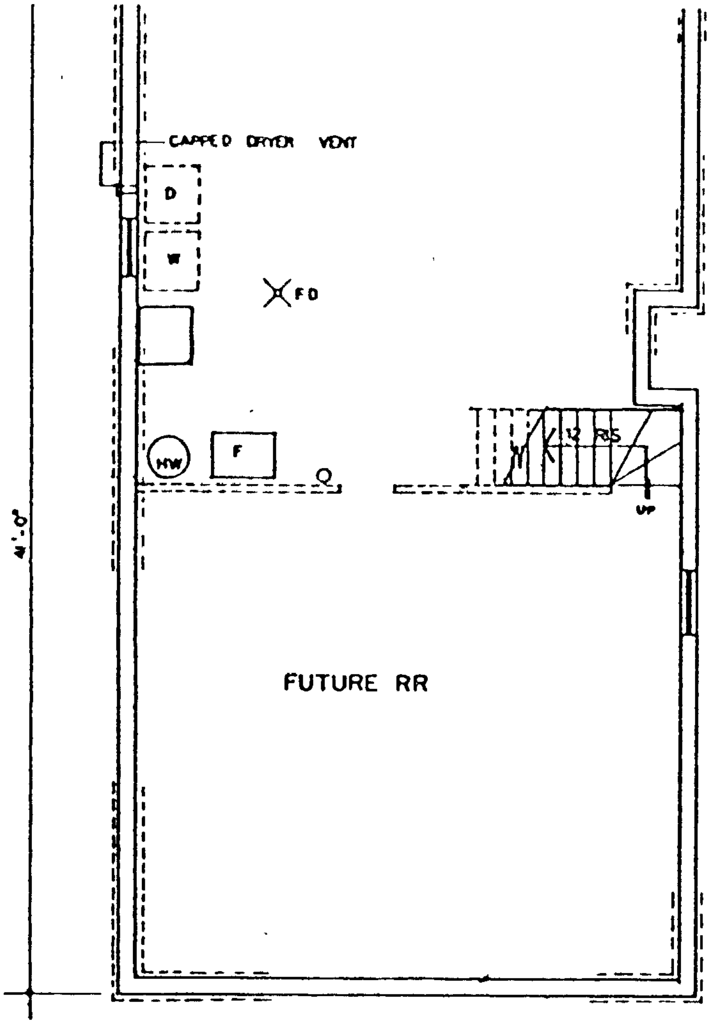
Figure 5

Dwelling Design 3.D.1. Type 3



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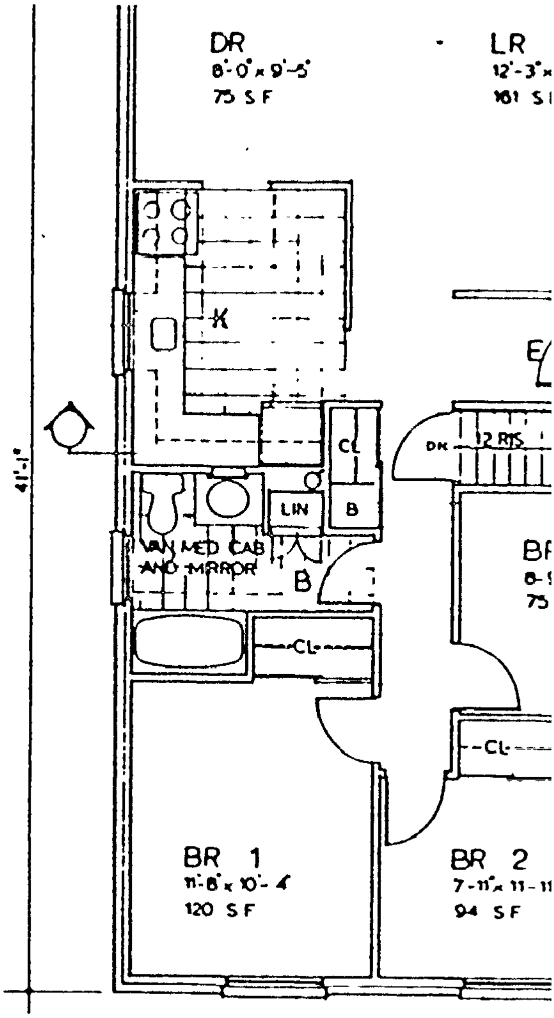

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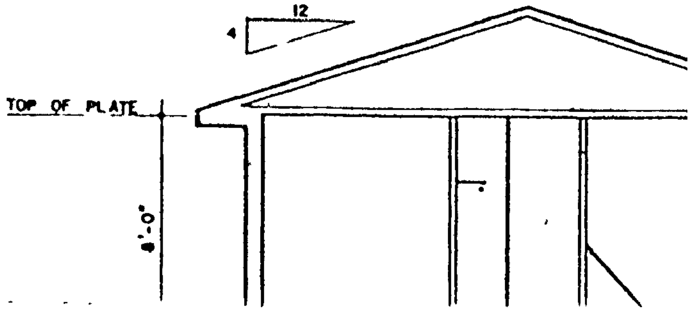

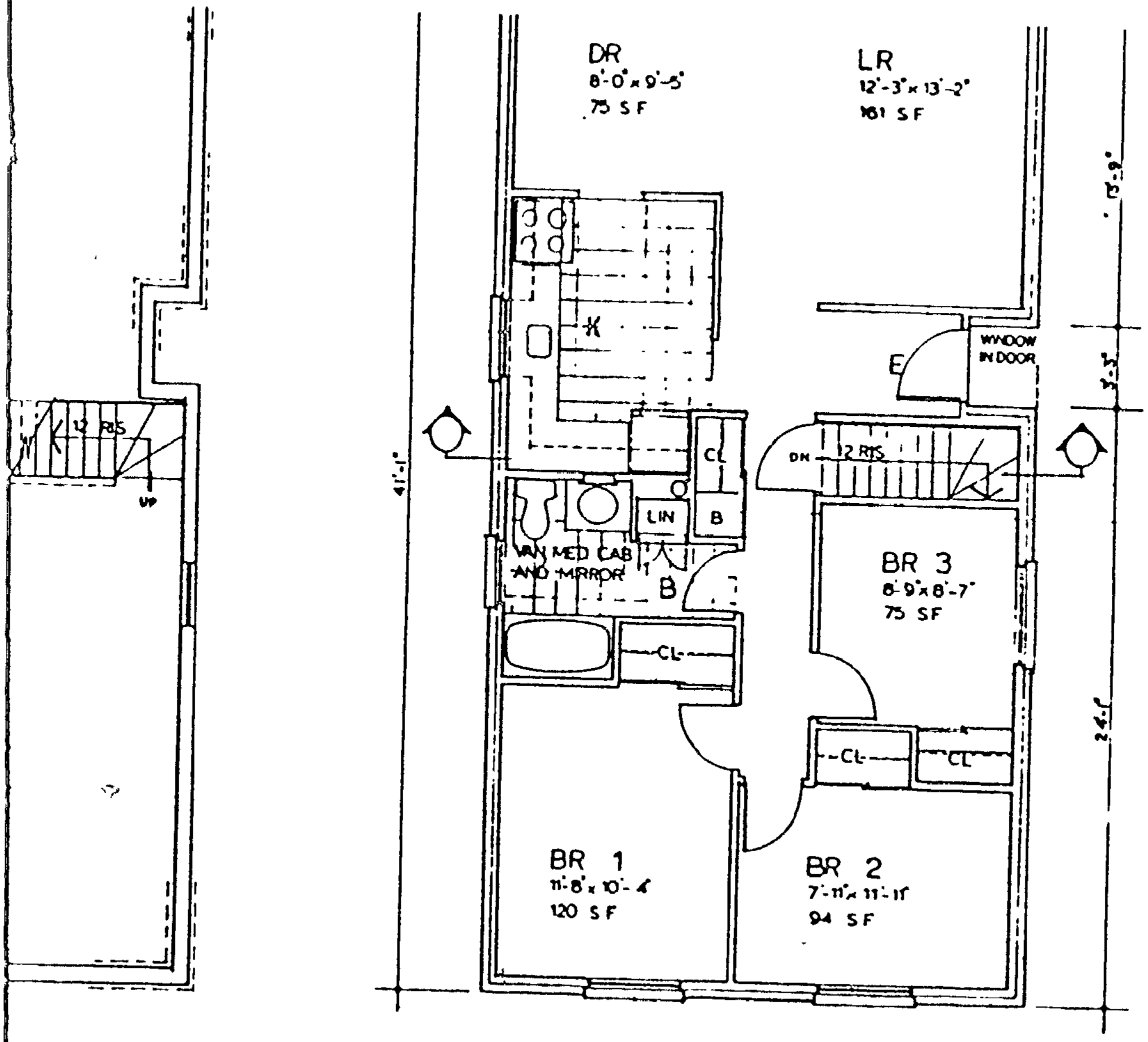

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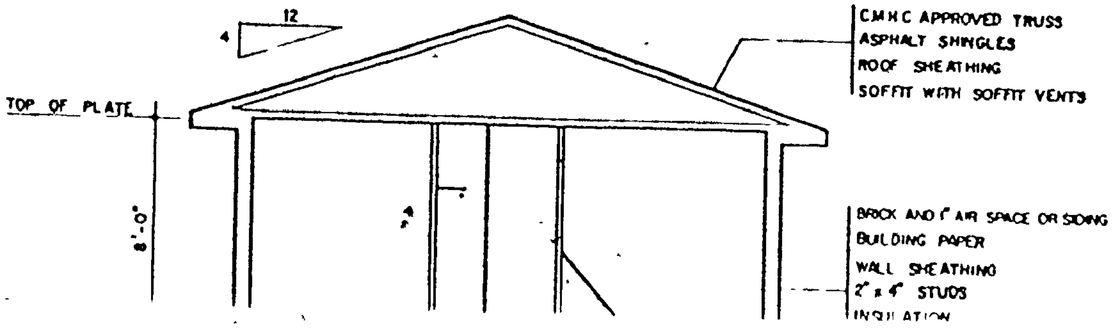

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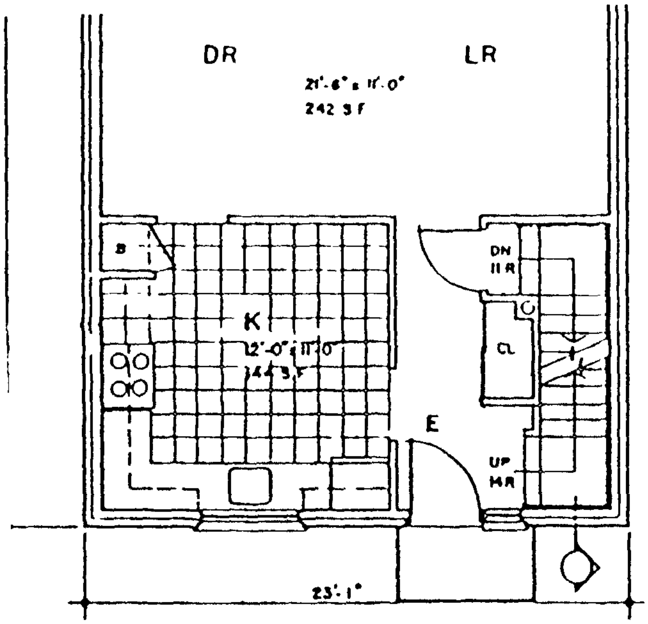
Figure 6

Dwelling Design 3.D.2.Type 2



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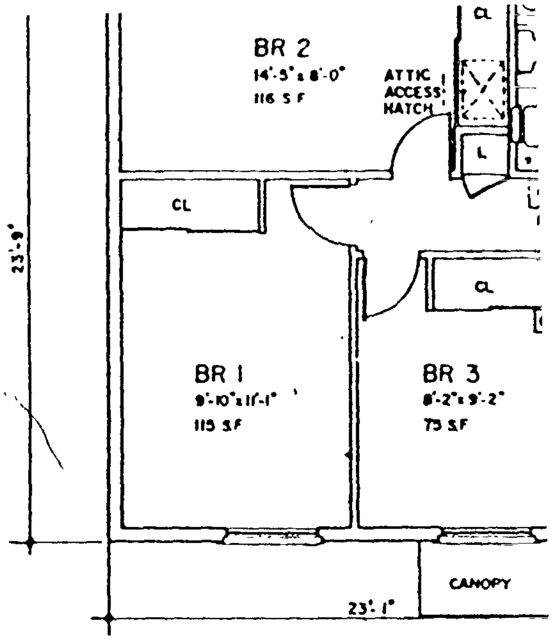
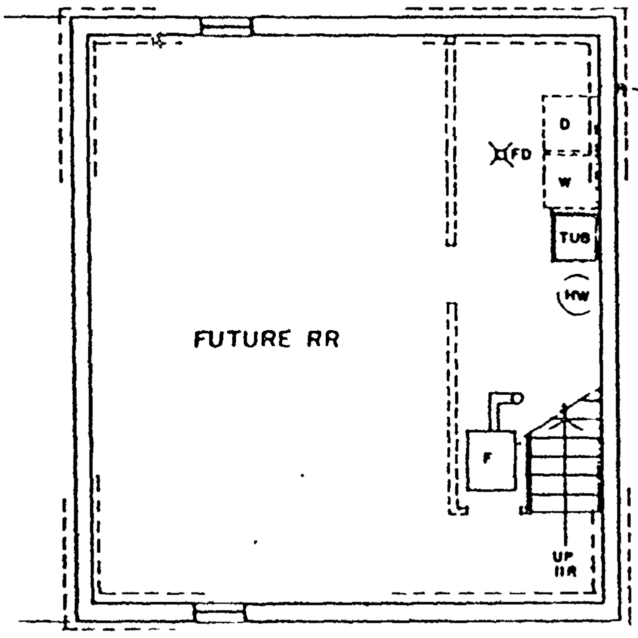
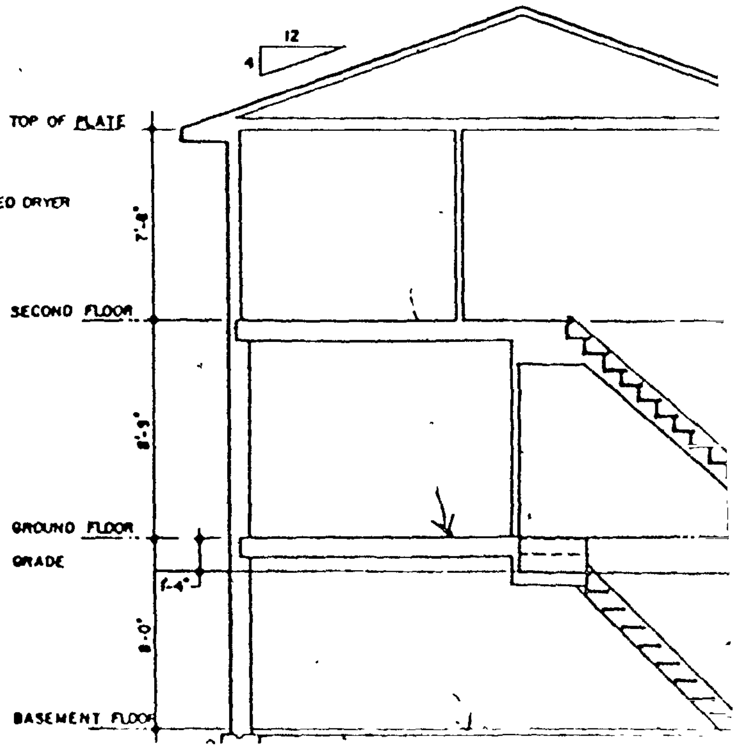
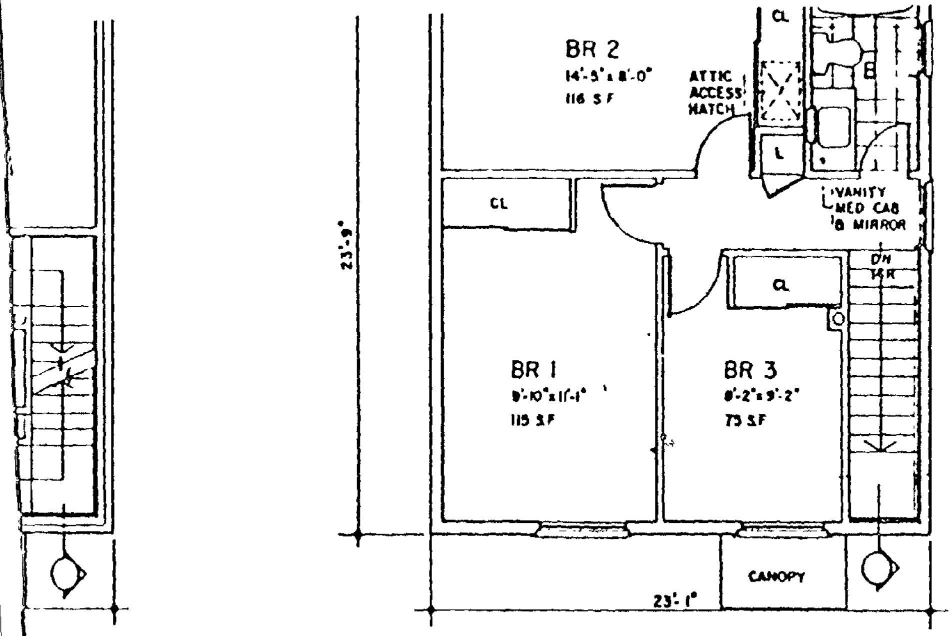


SECOND FLOOR PLAN







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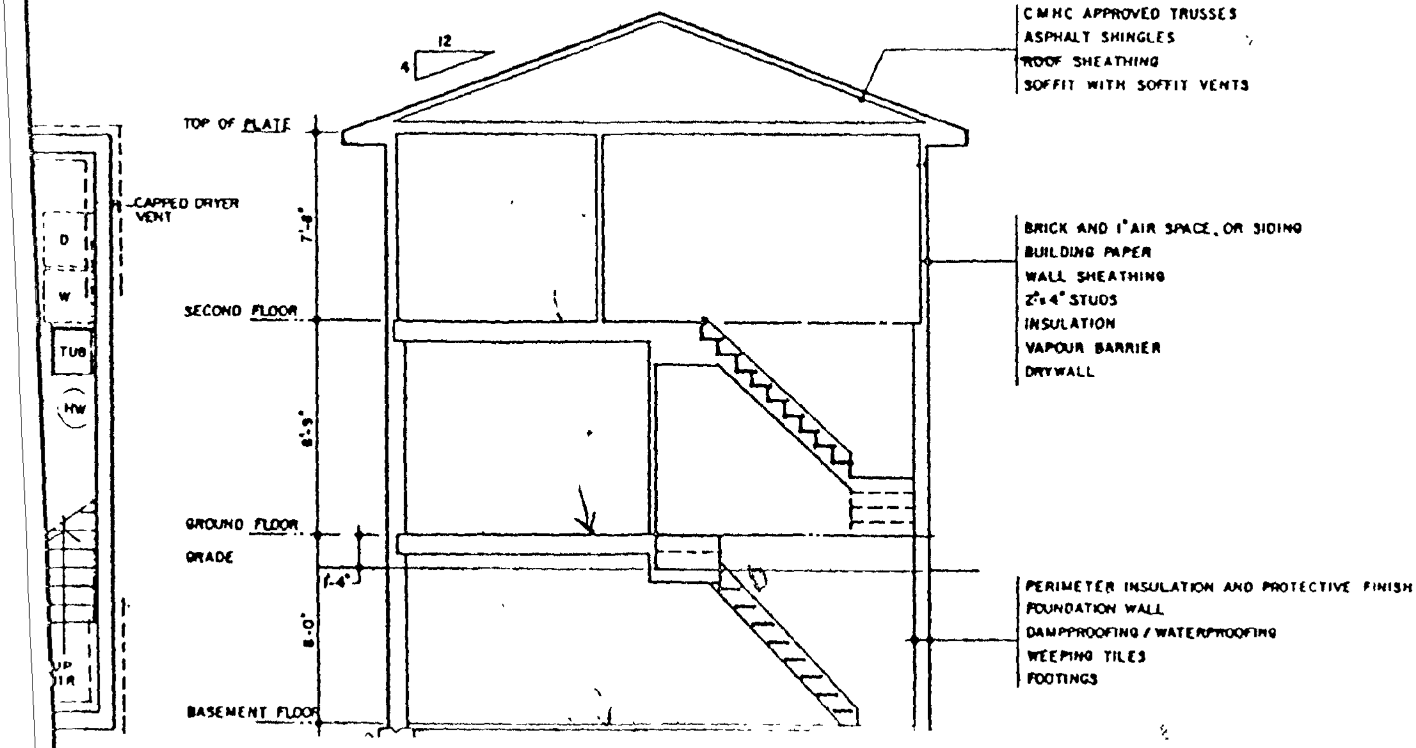
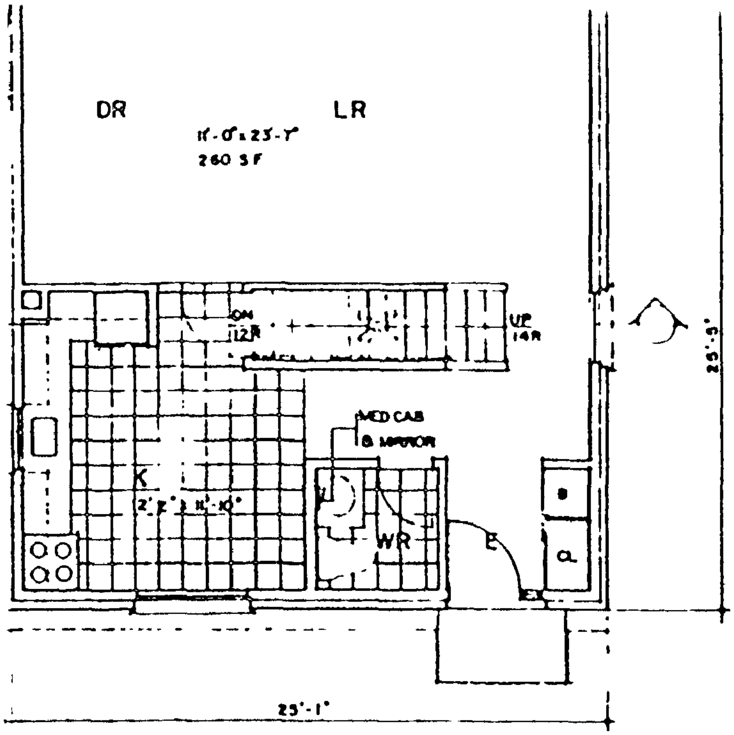


Figure 7

<u>Dwelling Design 4.D.2. Type 4</u>



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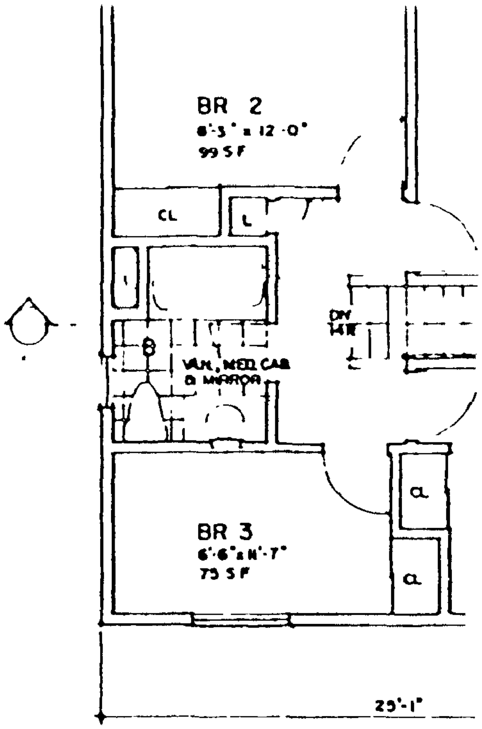

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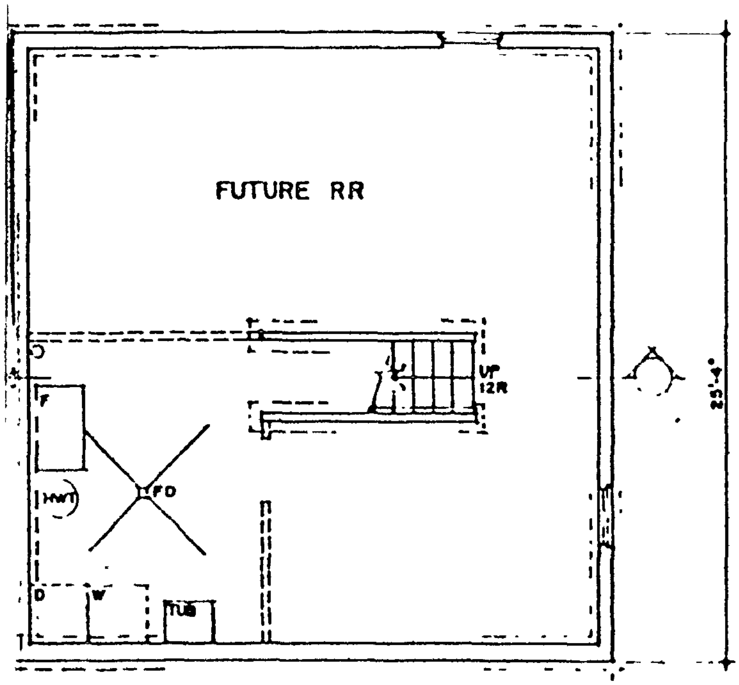

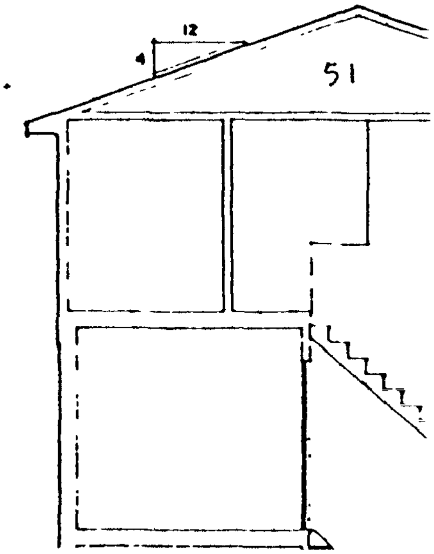

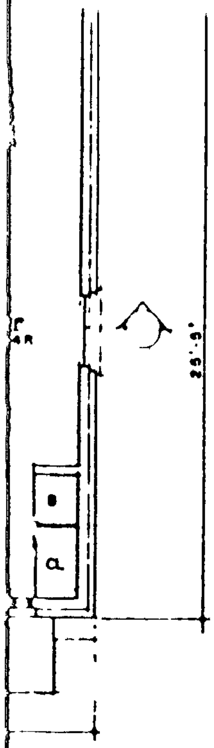

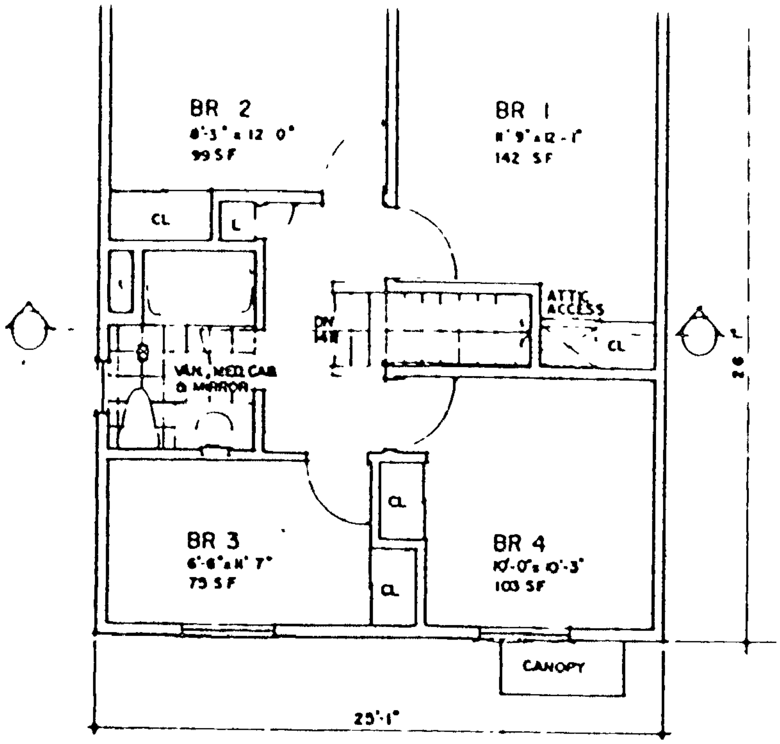

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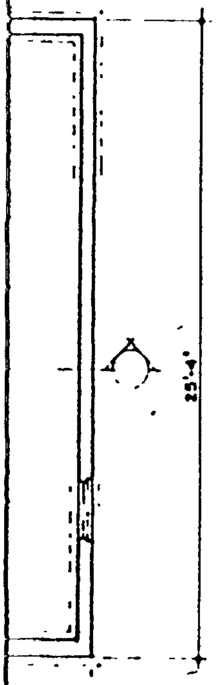

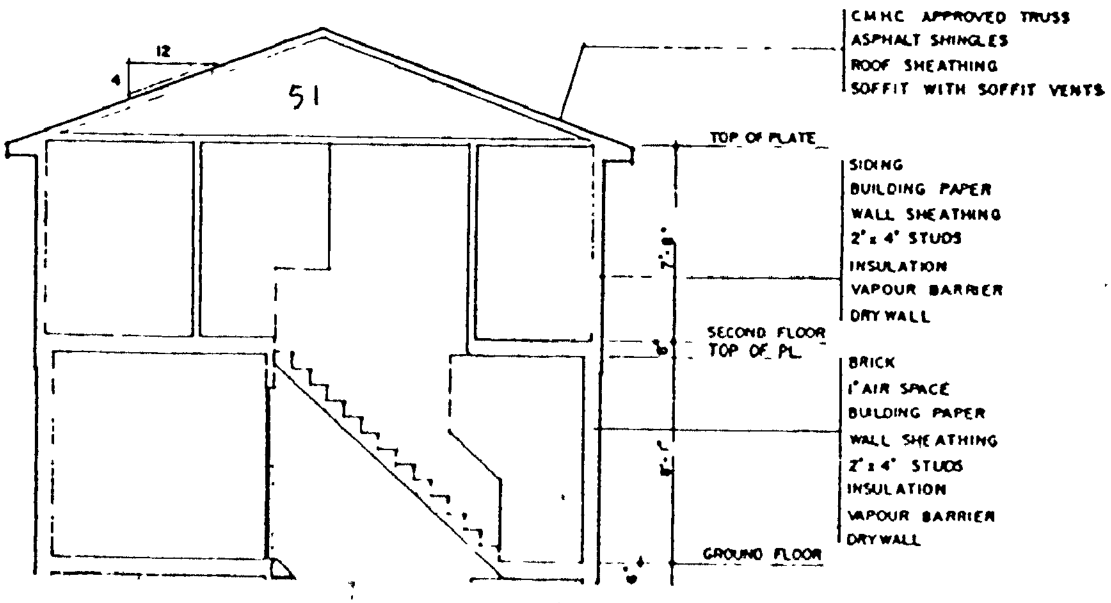

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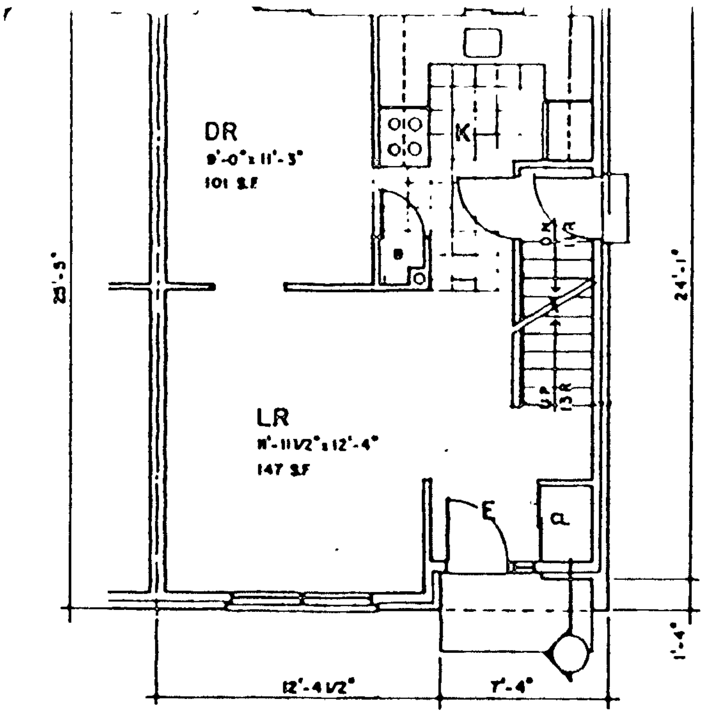
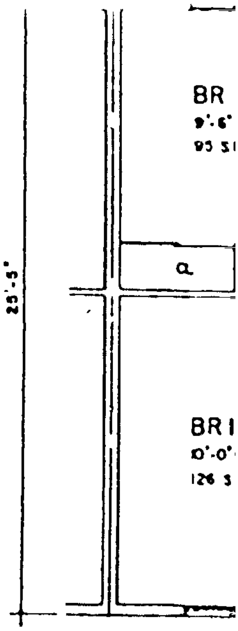
Figure 8

<u>Dwelling Design 3.SD.2. Type 2</u>



GROUND FLOOR PLAN



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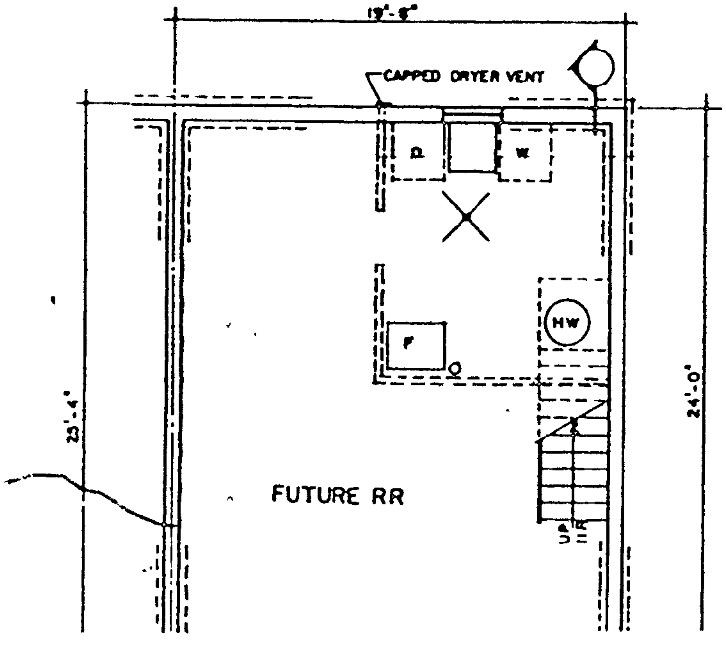

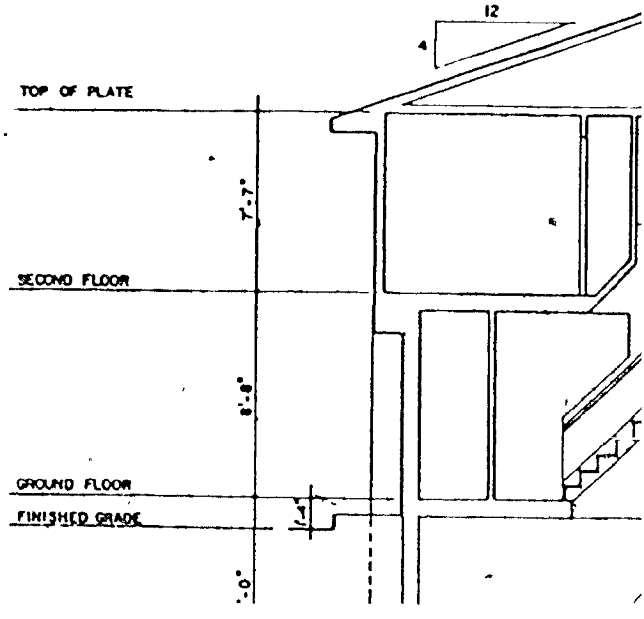

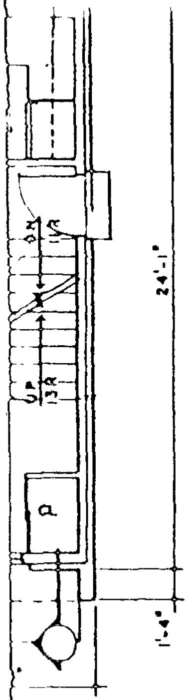

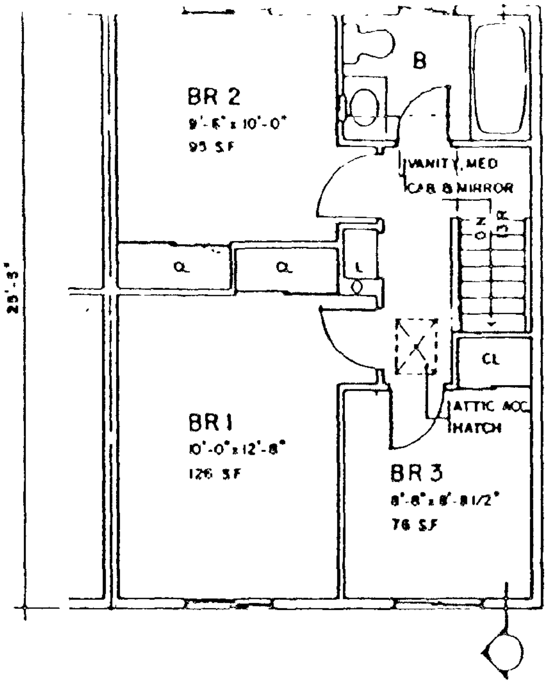

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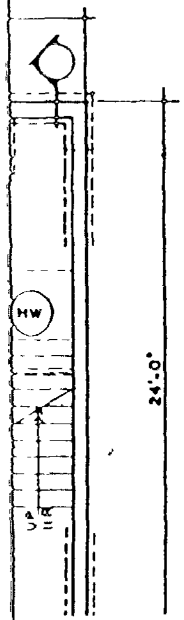

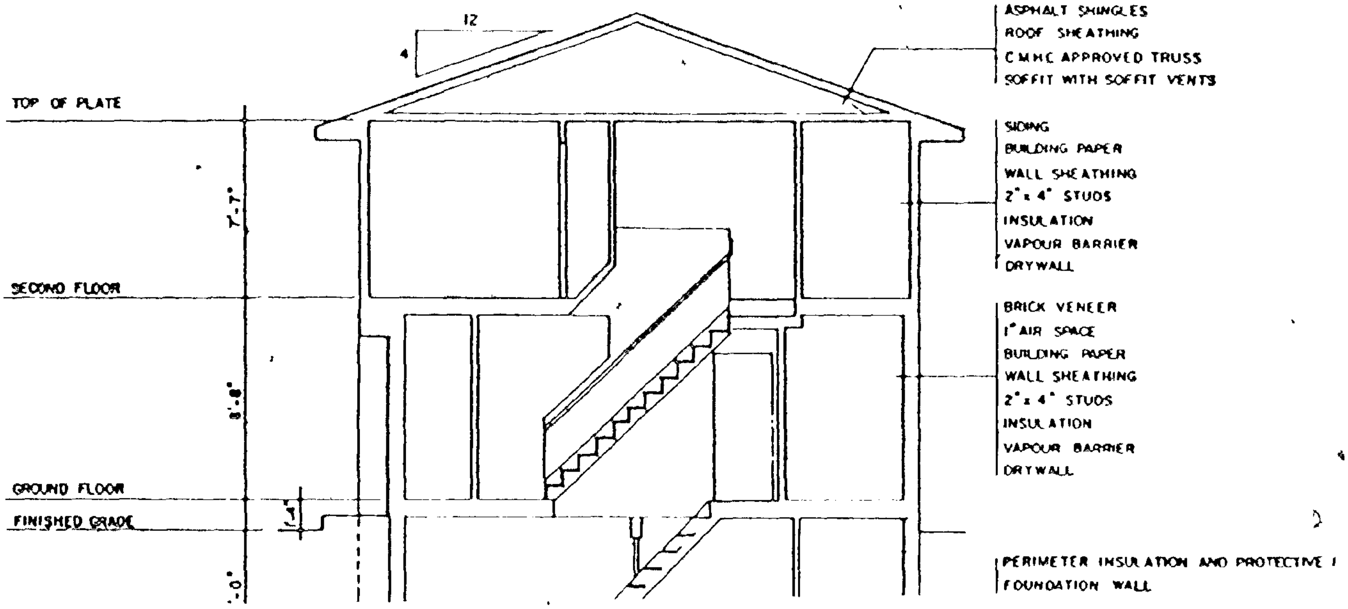

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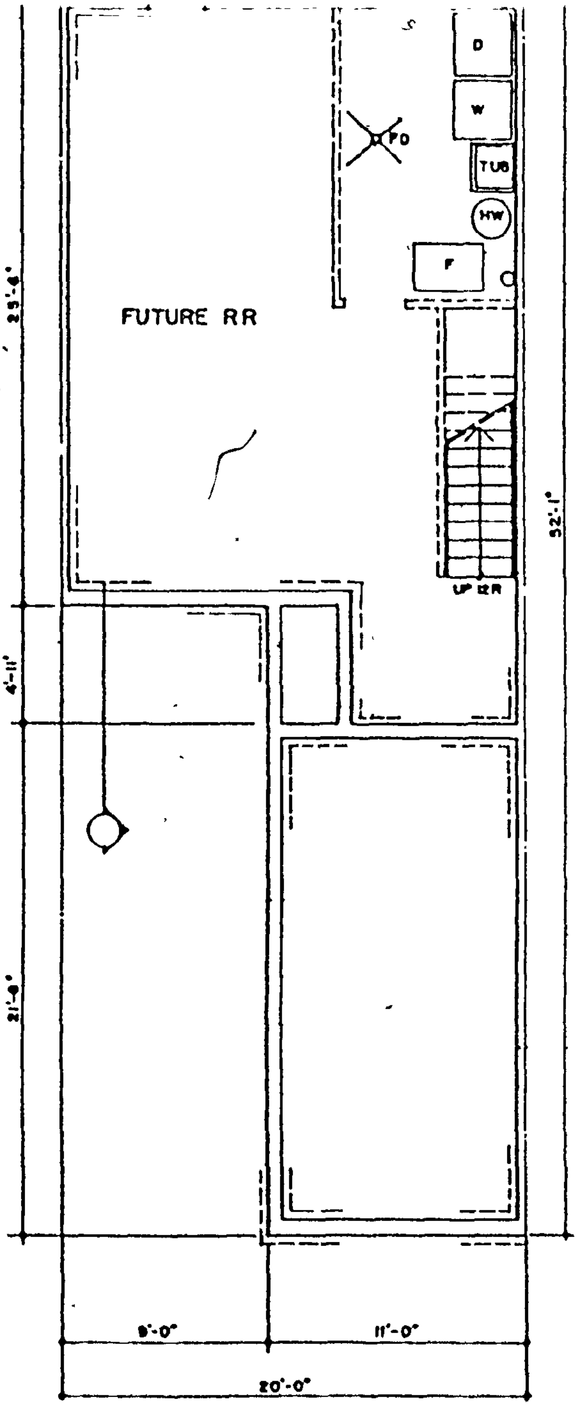
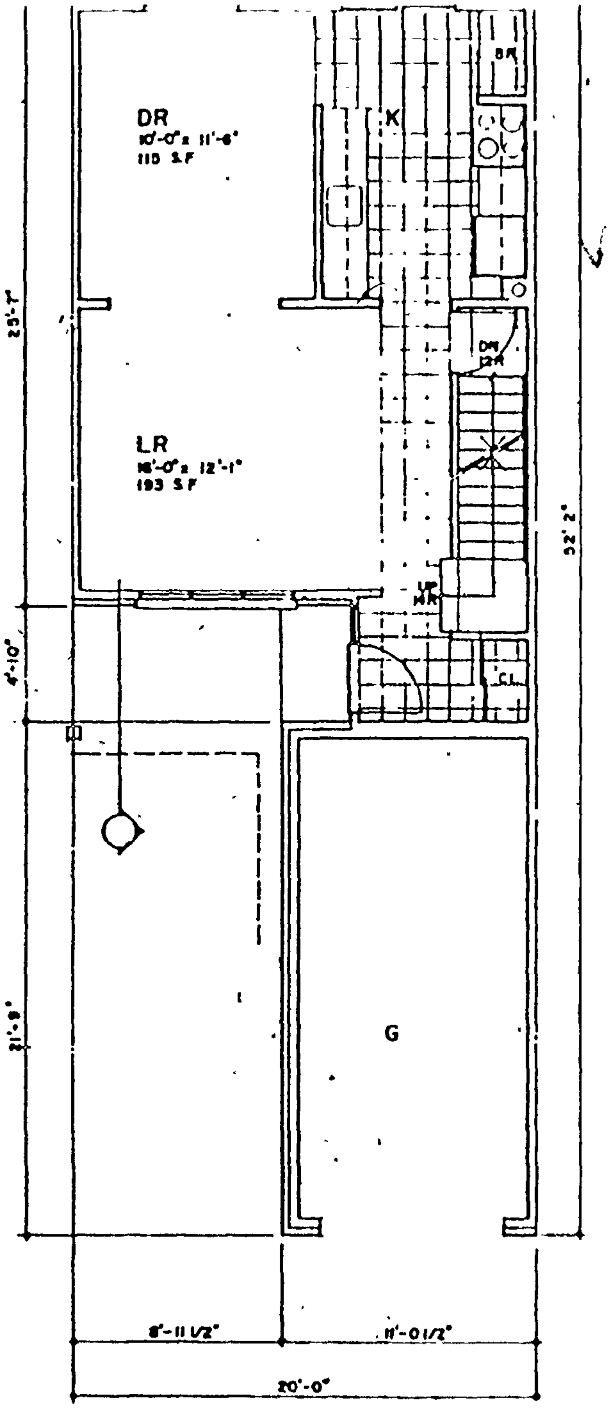
Figure 9

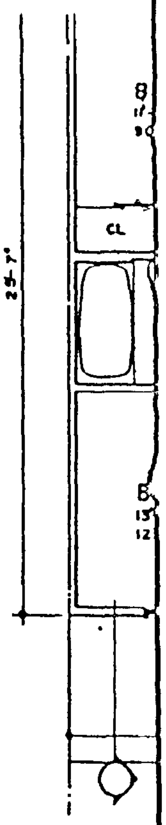
Dwelling Design 3.TH.2. Type 1



BASEMENT FLOOR PLAN



GROUND FLOOR PLAN



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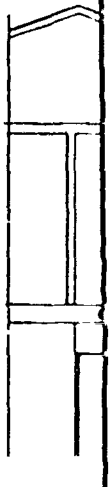

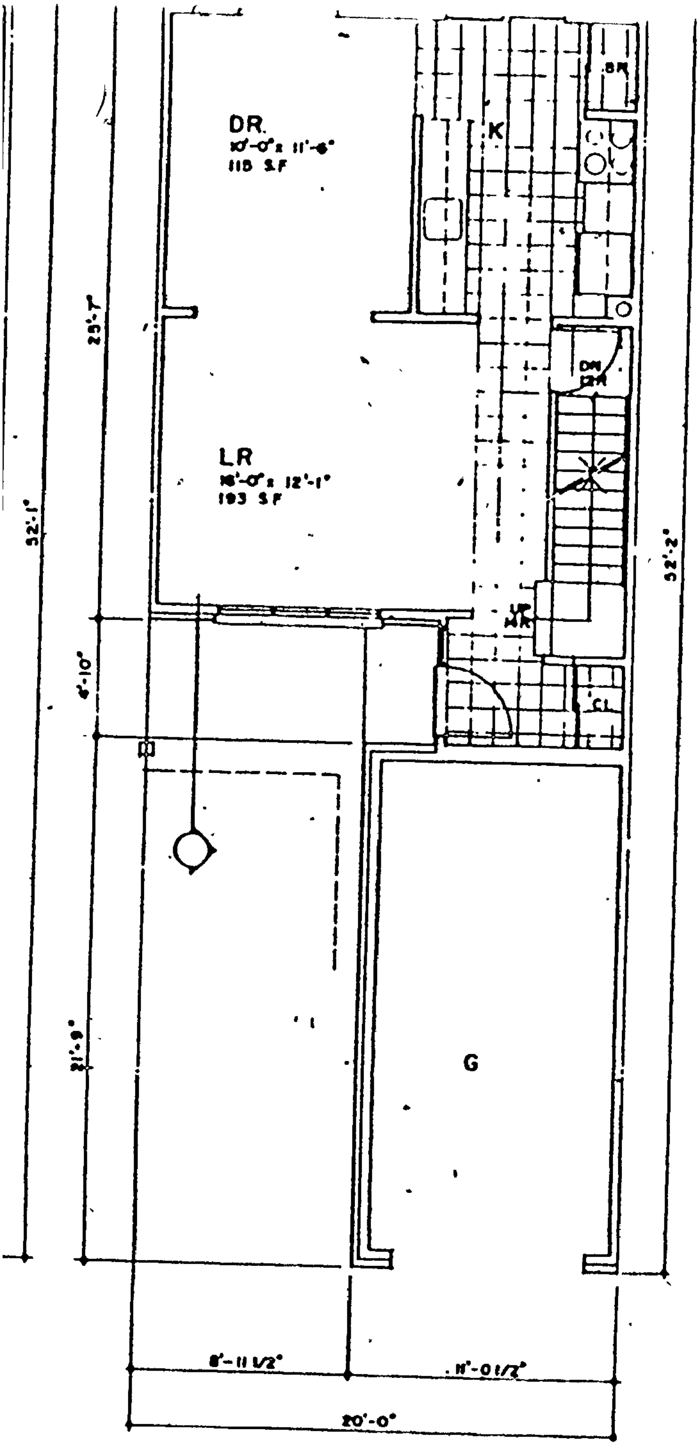

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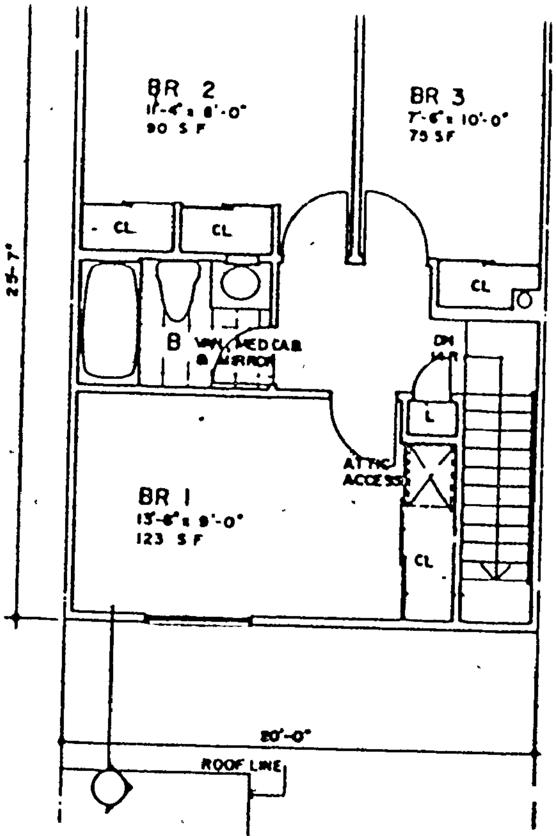

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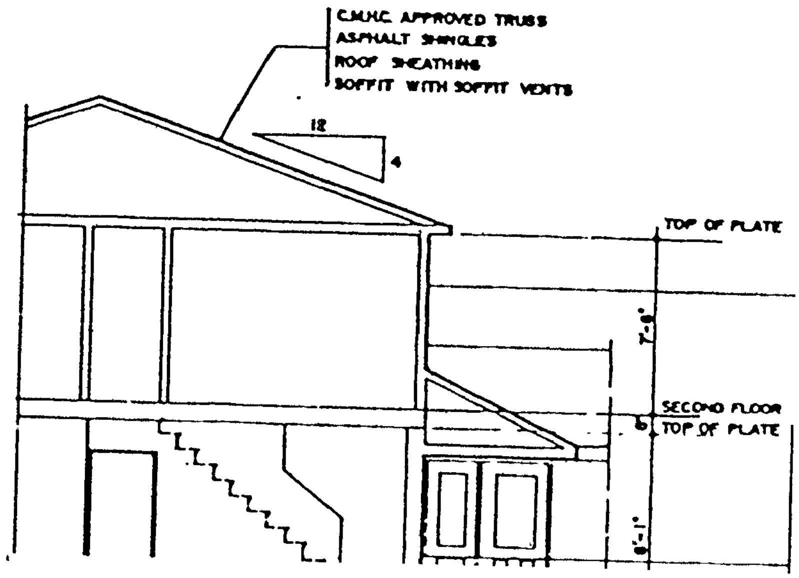

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Information on energy use for street lighting was obtained from Scarborough Hydro. According to that electrical utility, street lights in a residential subdivision are placed 125 feet apart and are lit for 4,300 hours per year per lamp. The road length of the subdivision is measured from the plan in Figure 3. Mercury vapour lamps have a wattage of 175. The street lighting consumption of the subdivision can be tabulated with this information.

d) Maintenance

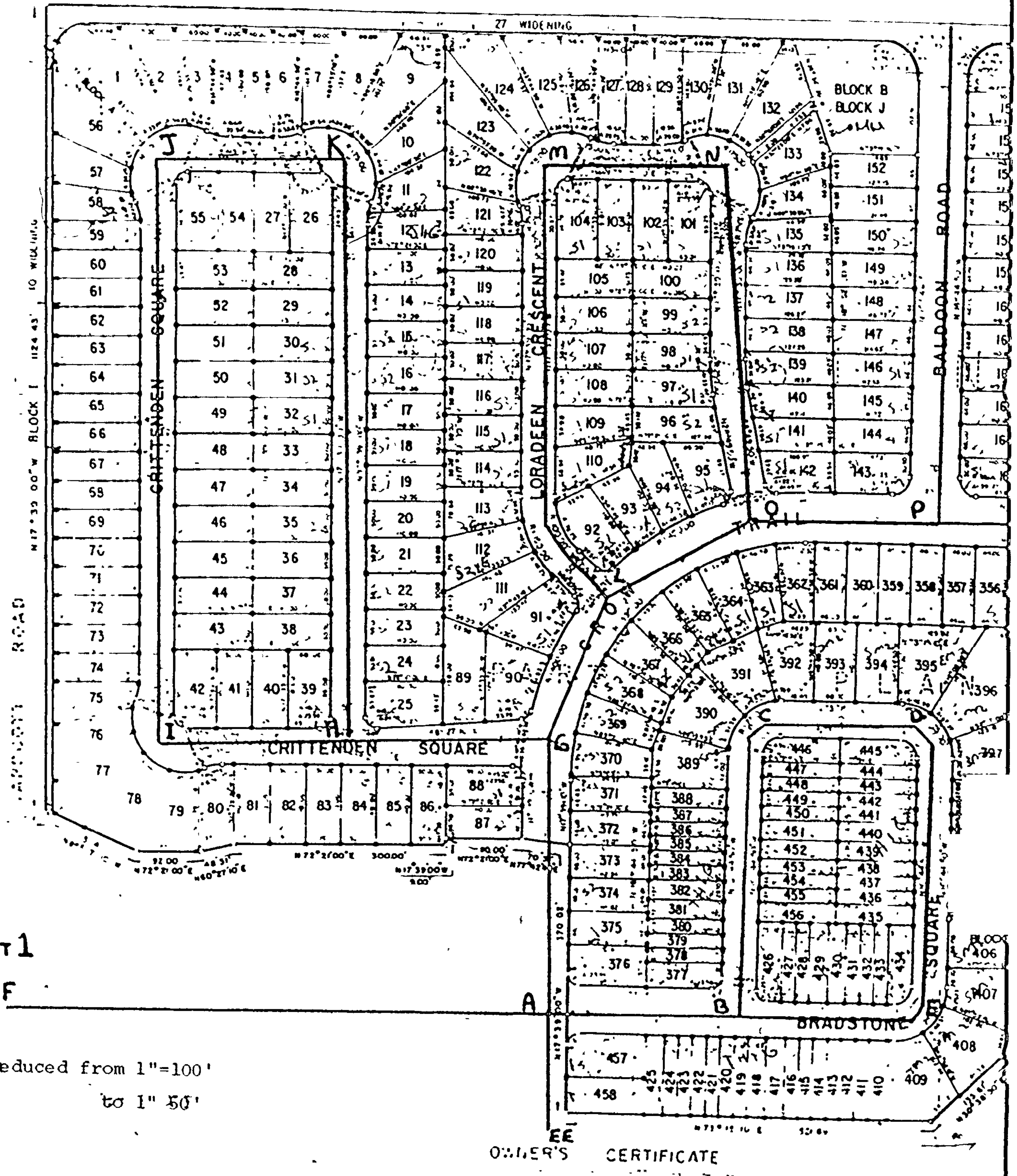
The Borough is just beginning to develop energy auditing procedures, and as such does not have readily available information on energy consumed for subdivision maintenance. However, an independent survey derived energy consumption data for water supply and sewage treatment. Energy consumed for snow removal and garbage collection can be calculated by multiplying average fuel consumption per gallon by the number of miles travelled in the subdivision.

e) Transportation

Middleton's method for forecasting transportation energy consumption within a subdivision was used. Figure 10 illustrates the zones that were demarcated. The distance between each home and the nearest arterial road was measured and multipled by the average number of trips per year per household. Middleton used transportation data from the Toronto Area Regional Modelling Study

Figure 10

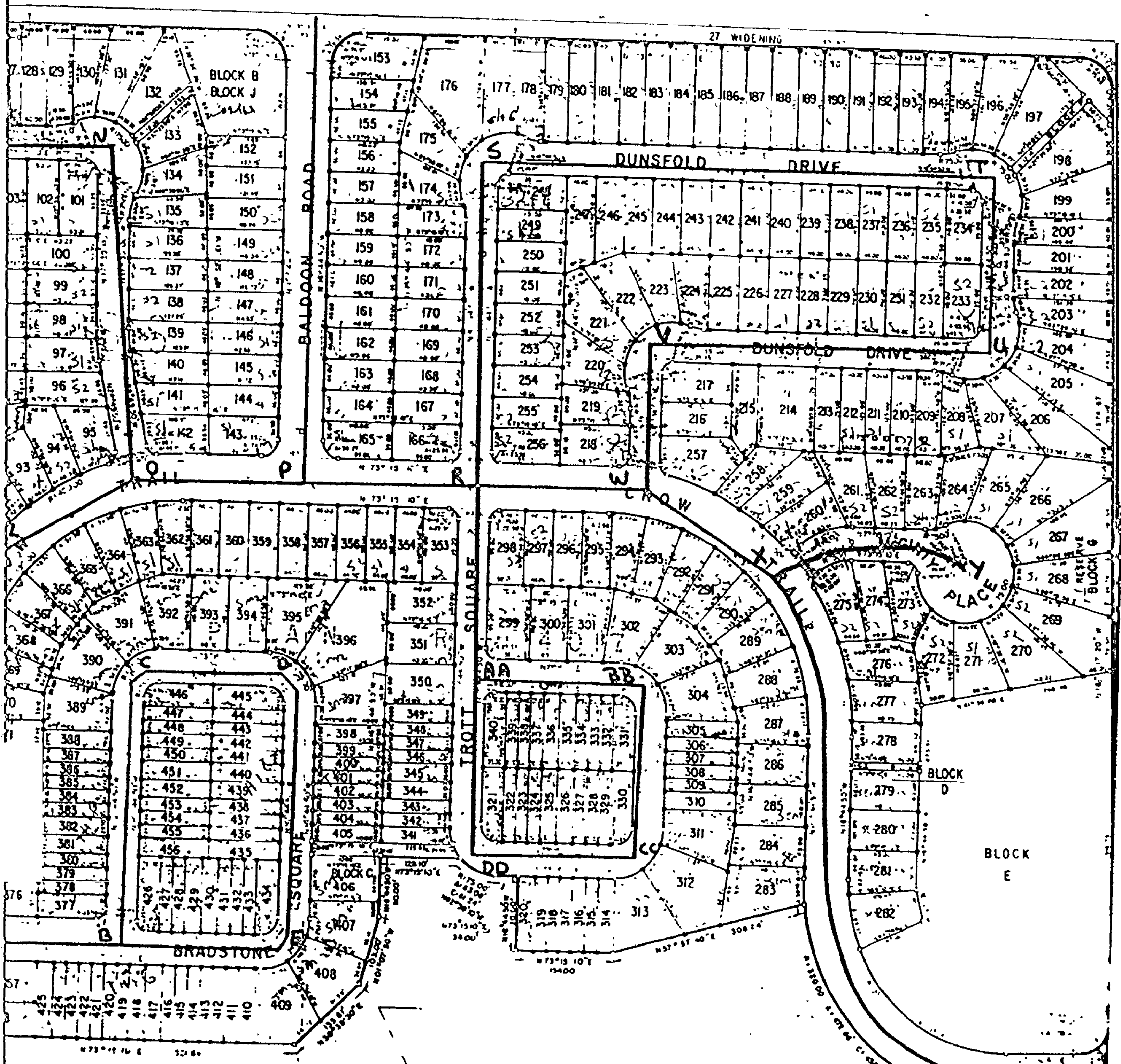
<u>Transportation Zones</u>



Exit 1

Reduced from 1"=100'

to 1" 50'



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(TARMS) within which the subdivision is located. This study uses data gathered in 1964, which could be outdated. However, this data was used for the energy consumption calculations in the absence of more recent data, recognizing its possible limitations.

These steps complete the energy inventory, and a summary of forecasted energy used for the housing development is illustrated in Table 2. Given the peak electricity and natural gas requirements, the local electricity and gas ulitity firms indicated that no new facilities were required other than extending nearby distribution lines.

3. Local Energy Standards

The Ontario Building Code regulates all building construction within the Province. All buildings must conform to its provisions, which include minimum thermal resistance standards, and conformance is ensured through mandatory building inspections. The houses therefore meet these Provincial standards.

The subdivision has also been developed to the maximum density permissible in the Scarborough Official Plan, and there are no other energy-related planning requirements.

Table 2

SUMMARY OF ENERGY CONSUMPTION

Type	Annual Use	Btu Comparison (Annual)	Peak Use	Btu/hour Comparison
Natural Gas	38.200×10^9 Btu	38.200×10^9	11×10^6 Btu/hour	11×10^6
Electricity	8,805,183 kwh	30.069×10^9	11,248,610 watts	38×10^6
Gasoline	18,751.8 gallons	27.977×10^9	--	--
Embodied Energy	411.042×10^9 Btu	411.042×10^9	--	--

4. Analysis of Alternatives

a) Embodied Energy

Opportunities for reducing embodied energy consumption are present in the amount of asphalt used, and in storm and sanitary sewer provision. Using Hannon's data, it was determined that 9.679×10^9 Btu could be saved by using two sixteen inch parallel paving strips instead of the conventional ten feet wide driveway. Roads and sidewalks are being constructed to the recommended minimum width, so further reduction cannot be achieved.

Eliminating storm sewers and designing for natural storm water drainage would save an additional 3.013×10^9 Btu. Sanitary sewers are being constructed to conventional standards i.e. ten inch pipe and connections to each lot. The Ontario Ministry of Housing's Urban Development Standards (1976)[34] recommends using eight inch pipe and having one connector for every two lots. The level of service to the household would be maintained, but the materials required for servicing would be reduced.

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[34] Ontario Ministry of Housing, Urban Development Standards (Toronto: The Ministry, 1976)

The embodied energy savings would be 3.946×10^9 Btu.

b) Space heating

Utilizing the options listed in Table 1, substantial energy savings for space heating are possible in the housing development.

The surface area to volume ratio cannot be reduced to any significant extent because the subdivision is designed to conform to the maximum permissible density, but advantage can be taken of other measures such as increased insulation, weatherstripping and caulking.

Savings of 3.036×10^9 Btu can be achieved by upgrading insulation beyond building code requirements to the standards recommend by the National Research Council of Canada. Weatherstripping and caulking are also significant energy savers. EMR Canada[35] suggests that infiltration can be reduced by 25 per cent due to these features, but a more conservative estimate of 20 per cent has been used in the calculations. 3.032×10^9 Btu savings are possible.

The subdivision is located in a province that has only a small amount of indigenous non-renewable fuels. It is therefore important that once the house is constructed in a manner that retains heat, the use of non-renewable fuels is minimized either

[35] Energy, Mines and Resources Canada, 100 Ways to Save Energy and Money in the Home (Ottawa: The Ministry, 1975)

through substituting with renewable energy forms, or maximizing the efficiency of the energy converter (furnace). Gas furnaces are proposed for the subdivision, and the most efficient furnaces will be used. Replacing gas furnaces with electric furnaces or heat pumps would save 14.017 x 10^9 Btu and 28.884 x 10^9 Btu respectively but the question of the source and efficiency of electricity supply and distribution must be considered. Although a true comparison between system efficiencies cannot be made because the efficiency of natural gas distribution is unknown, it is relevant to know that electrical generating stations are generally only 30 per cent efficient and could be using non-renewable fuels to generate the electricity. This being the case, the energy savings attributable to electric heating would be reduced substantially to 4.205 x 10^9 Btu (14.017 x .30) and 8.665 x 10^9 Btu (28.884 x .30).

Setback thermostats reduce the amount of time that a furnace is operating and if used in this development, could save 6.365 x 10^9 Btu annually.

Passive and active solar systems were considered with respect to their potential energy saving, and based on savings of 50 per cent to 100 per cent for each system respectively, the annual savings would be 19.761 x 10^9 Btu or 39.523 x 10^9 Btu.

These systems cannot really be considered as alternatives, however, as the technology is not sufficiently well developed that the systems are reliable or could be readily constructed by builders.

c) Lighting

Incandescent lighting is proposed for the houses in the subdivision. Fluorescent lighting, however, is five times more efficient and if utilized would result in a reduction of 301,381 kilowatt hours of energy use annually. Replacing proposed mercury vapour street lighting with high pressure sodium lighting would result in reduced demand of 7500 watts and an annual savings of 32,250 kilowatt hours.

d) Water Heating

Electric water heaters are proposed and again the most efficient heaters available would be used. Restricted flow faucet fittings can reduce water use by 15 per cent, which would result in energy savings of 447,300 kilowatt hours annually and a reduction in demand of 335,475 watts.

Solar water heating systems were also considered, as experiments have shown that 70 per cent of water heating requirements can be provided by solar systems. Based upon this percentage, the potential energy savings are 1,565,550 watts and 2,087,400 kilowatt hours annually. Solar water heating systems are, however, still at the experimental stage and, like passive and active solar space heating systems, cannot yet be considered as an option.

e) Maintenance and Transportation

These two elements are considered together here as the maintenance energy costs of snow removal and garbage collection relate directly to the length of roads to be serviced. No alternatives will be recommended because, as discussed earlier, there is no available method for determining alternate road patterns that would minimize distances to arterial roads.

5. Mitigation Measures

Table 3 summarizes the potential energy savings that could be achieved by including the options listed. Kilowatt hour figures have been converted to Btu to allow for comparison. Table 4 lists the changes which could be required to the development, in order of priority.

Energy Use Investigation and the Planning Process

One of the keys to the success of an energy use investigation methodology is its ease of application to an established process. Ease with which the methodology is incorporated into planning procedures will determine the extent to which it is used. This section will describe, generally, the planning process as it exists in Canada and the U.S. with particular reference to Ontario, as the Province of the case study, and will suggest how an energy investigation procedure can fit into this process.

Table 3

SUMMARY OF POTENTIAL ENERGY SAVINGS

Embodied Energy	Savings Btu x 10^9	Btu (x 10^9) Comparison	% Savings Over Proposal
Driveway Strips	9.679	9.679	75
Natural Drainage	3.013	3.013	100
Smaller Sanitary Sewers	3.946	3.946	44
Space Heating			
Weatherstripping and Caulking	3.032	3.032	7.9
Insulation	3.036	3.036	7.9
Setback Thermostat	6.365	6.365	16.6
Electric Furnace	14.017(4.205)*	14.017 (4.205)	36.7(11)
Heat Pump	28.884(8.665)	28.884 (8.665)	75.6(22.7)
Lighting			
Fluorescent	301,381 kWh	1.028	80
Mercury Vapour	32,250 kWh	110	43
Water Heating			
Restricted Flow Fittings	447,300 kWh	1.526	15

* Brackets indicate that energy supply system inefficiency has been taken into account.

Table 4

MITIGATION MEASURES

Measure	Savings Btu X 10^9
1. Driveway Strips	9.679
(2. Heat Pumps)*	(8.665)
3. Setback Thermostats	6.365
(4. Electric Furnace)	(4.205)
5. Reduce Sanitary Sewer Size	3.946
6. Increased Insulation	3.036
7. Weatherstripping and Caulking	3.032
8. Natural Drainage	3.013
9. Restricted Flow Faucet Fittings	1.526
10. Fluorescent Lights	1.028
11. Mercury Vapour Street Lights	.110

* Electrical energy supply system inefficiency has been taken into account.

As discussed earlier, the development of energy impact assessment is largely an outgrowth of the U.S. National Environmental Policy Act. As such, there are limitations to its application by adhering to the NEPA framework. While environmental assessment regulation is sufficiently flexible to include energy concerns, in both Canada and the U.S. the requirement for environmental assessment is limited mainly to public sector projects and to some specified private sector projects. Thus, by confining energy analysis to this framework, many developments which could have large potential for energy savings would not be subject to an investigation of energy use.

The responsibility for land use planning in most of North America lies with municipal governments, within the policy framework of senior government levels. Municipalities are charged with regulating the use of land in their jurisdictions and have far-reaching powers over all development that takes place within their boundaries. For example, in Ontario, where the case study is located, municipalities have a variety of legal tools for regulating development, and these tools can be utilized in different ways for incorporating an investigation of energy use.

The Planning Act[36] requires municipalities to prepare official plans which outline policies for the deployment of land,

[36] The Planning Act, Revised Statutes of Ontario, 1970

and grants authority to regulate development through zoning, site plan bylaws and subdivision and development agreements. The normal process of planning approvals requires the proponent of a project to submit to the local planning agency a description of the proposal with perspective drawings of the buildings.

The proposal is then evaluated against planning criteria established in the official plans and bylaws. These criteria normally include restrictions on location, density, building height and situation of the building on the lot, and can control external design of the building. It is at the plans approval stage that an energy investigation would most easily and appropriately be incorporated.

Municipalities have the greatest degree of control over development, so are the logical agencies for evaluating the energy characteristics. Energy use could become another planning criterion by which proposals are evaluated, like location, density and height.

The nature of planning in Ontario is such that landowners must justify the way in which they use the land, and elected or appointed officials are responsible for the final decision on land use. Therefore, evaluating development proposals against planning standards often requires that the proponent prepare, at his own expense, studies or reports on any matter pertaining to the development that is desired by a municipal council. It is common for a developer to submit with his proposal studies on topics such as soil type, traffic, noise and environmental impact. An energy inventory could be included as a development characteristic for which the proponent would provide information, both because it is a logical extension to current planning practices and more importantly, because the developer is largely responsible for the level of energy use of the project. Upon submission of the energy use analysis, the planning department could compare the energy use with energy saving alternatives. Municipalities are limited, however, in the extent to which they can prescribe mitigation measures. Municipalities do not have the legal authority to require changes to house construction details, as these are regulated by the Ontario Building Code. Therefore, they could not require more efficient furnaces or water heaters, increased insulation, weather stripping and caulking, fluorescent lighting, or use of alternative fuels or supply systems. These changes could only be required by revising the code, which must be a Provincial initiative.

Municipalities could, however, influence the builder to voluntarily improve the energy characteristics of his houses. Making public the results of the investigation of energy use would indicate to prospective house buyers any energy saving features which were not included in the development. Disclosing the energy characteristics could raise the awareness of the purchasers, and possibly create a demand for more energy conscious development. Municipalities can legally require this disclosure. Municipalities can also require reduced road and sidewalk width, reduced length of servicing pipes, changes to road layout, and changes related to density, location of development, orientation and site planning.

In the case of housing developments, the proponent of the project is often not the final builder of homes. A developer, in many cases, will acquire the land, negotiate the required approvals, provide services such as roads, sewers, and surveying, and sell the lot to a builder or builders with certain conditions attached. The conditions will normally include the planning criteria mentioned earlier, such as building height, setbacks of buildings from the lot lines, size of lot and number of units per acre. Adding new criteria to the planning approval stage, such as housing design and internal layout, will result in additional conditions being attached to the sale of lots. As such the building industry would have to respond to the new requirements.

The energy consumption of street lights was included in the evaluation, yet street lights are normally installed by the local electrical utility and not the developer. Recommending operational changes to outside agencies other than developers would be a departure from the standard planning process, and may not be accepted as part of the energy investigation procedure.

Projects of senior levels of government constitute a separate category of proposal, as they are legally not bound by municipal planning regulations. They should nevertheless be subject to an investigation of energy use. The framework already exists in Ontario to undertake assessments of projects with the Ontario Environmental Assessment Act.[37] This procedure has come under criticism for its ineffectiveness, primarily because few assessments are actually carried out. Regardless of its shortcomings, the existing framework should be utilized for the energy investigation of government projects to avoid the problems associated with creating a new regulatory structure. Also, the environmental assessment procedure addresses the question of alternatives to the project i.e. whether or not the project should be permitted at all. This issue is one which requires the examination of a broader range of factors than is considered in energy assessment, but is one for which the energy investigation could provide valuable input.

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[37] The Environmental Assessment Act, Statutes of Ontario, 1975

This approach to reducing energy use and improving energy efficiency is essentially reactive, which by itself is contrary to normative planning. Ideally, an energy use investigation would form only one component of an overall approach of ensuring appropriate levels of energy use.

This approach could include, from a land use planning perspective, adopting official plan policies and zoning bylaws that foster more efficient forms of development (e.g. allowing the mixing of land use types to reduce the need for transportation, requiring medium densities) and from a broader government perspective, could include leadership by example and incentives, among other examples.

In summary, the methodology could be accommodated within the existing regulatory framework for assessing new developments, but a number of significant energy-saving features could be legally required only through changing existing legislation. At the Provincial level, where energy use statements would be prepared by the government agencies themselves, the assessment becomes an additional task for which additional resources and technical skills are required. At the local level, municipalities would be required to request that energy inventory statements be prepared by proponents of development and to compare the statement with alternatives. Investigating energy use requires a commitment of time and resources which is common for all types of regulation. Yet these extra costs could be minimized as the methodology could fit into an existing system.

V. CONCLUSIONS

This thesis was undertaken to determine the feasibility of developing a residential energy use investigation methodology. The approach taken was to assess previous experiences with this type of methodology, which highlighted the need for predictive methods for measuring energy use. These methods were then identified, and a review of an associated field of literature was made, to determine if there were similarities. Based upon this information, a methodology was recommended, and subsequently tested to determine the validity of the recommendations.

It was found, in the review of past experience with attempts to investigate residential energy use, that while there were requirements in the legislation to assess energy use in all types of projects, few guidelines existed as to how this assessment should be carried out. The State of California requires that environmental review reports that are prepared to fulfill the provisions of the CEQA include an investigation of energy use. The investigation must consist of an energy inventory, a discussion of alternatives, and potential secondary impacts. This provides the beginnings of a framework for evaluating energy use, but does not offer specific means of conducting the investigation. The State guidelines often conform closely to NEPA requirements, which results in their being focussed upon broader energy impacts, rather than upon investigating energy consumption.

Contra Costa County was found to be the most advanced jurisdiction with respect to residential energy use evaluation. The County's procedure clearly spells out the information requirements yet the procedure does not suggest how the information is to be obtained (e.g. what predictive methods should be used) nor does it state how the alternatives will be evaluated. The procedure, therefore, is not rigorous in quantifying energy savings, which is a shortcoming that could result in inappropriate mitigation measures being required.

A method for preparing energy impact statements was developed by Blair Folsom and was examined closely in the thesis. This method adheres closely to the NEPA requirements e.g. investigating the impact of energy consuming projects rather than evaluating the energy use, but it offers some otherwise valuable recommendations on the process and suggests some methods for quantifying energy use. The method is similar to the State of California guidelines in that it recommends preparing an energy inventory and a description of alternatives and potential energy savings. It also emphasizes, however, the need to state how the alternatives will be assessed, that is, a means of determining which should be considered and possibly required. This insight is important in assessing energy saving options in a housing development, as the range of options is considerable, but not all of the options are feasible for various reasons.

The review of these different experiences indicated that there was a need to identify methods for forecasting energy use for the energy inventory phase, and for assessing the alternatives. A literature search confirms that various methods were available for measuring and forecasting energy consumptions but that there were areas where methods have yet to be developed.

Bruce Hannon's research into embodied energy consumption gives detailed data for measuring the amount of energy that is used to provide services such as roads, sewers, and sidewalks, as well as driveways. However, only gross energy consumption data is available for embodied energy on a housing unit basis.

A variety of methods are available for predicting space heating energy consumption. The ASHRAE Modified Degree Day Method was selected for the case study, but other methods could be used, provided that detailed calculations and assumptions are supplied. The drawback of this particular method is that it does not take into account differences in household characteristics such as family size and age, so the final energy consumption figures will not be totally accurate. This does not affect the procedure, however, as changes to household characteristics cannot be changed with this methodology, so the comparative savings in energy between the proposed development and the alternatives would remain the same.

Water heating, lighting, and appliance data was readily available, based upon actual measurements of energy consumption. Maintenance energy consumption data is not available for all municipalities. For that which can be obtained, it is difficult to determine the alternatives available, because of the many possible ways of designing street layouts to reduce travel distances for servicing equipment.

Transportation energy consumed as a result of the housing development can be forecast for trips internal to the subdivision. The energy use for all other trips cannot be predicted, however, without information on journey to work trips and non work trips.

Despite shortcomings in some of the predictive methods, there was sufficient information upon which to base an investigation of energy use. The energy use of the example housing development was compared with possible alternative forms of development. In order to do this it was necessary that there be methods for predicting the possible energy savings of the alternatives. Out of the broad range of energy saving alternatives that were identified, only a proportion were found to be quantifiable. The energy savings of these alternatives were easily seen through quantification, yet the energy savings of the remaining alternatives cannot be measured until predictive methods are developed.

One shortcoming of the methodology is that it does not have a built in procedure for determining which alternative features it would be acceptable to require. Beyond the measuring of energy savings and efficiency improvements, a decision must be made as to whether it is desirable to consider alternatives which may have secondary impacts such as increasing house prices or environmental problems. The methodology does, however, allow for the energy saving attributes of the alternatives to be compared, which could in turn influence community attitudes towards the alternatives. The methodology also reveals difficulty in determining the supply system inefficiency, which makes the comparison of alternatives less accurate. Identifying the source of electrical generation (e.g., oil, coal, hydraulic) will affect the choice of alternatives, but until methods for measuring these inefficiencies are known, or until it is known that they are significant, this problem cannot be overcome.

An examination of critical reviews of environmental assessment methodologies suggested a number of principles that could apply to an energy use investigation, and the case study bore out these suggestions. The most important elements to a methodology were considered to be accuracy and objectivity. The various sources recommended that predictive methods used should be clearly described and that detailed information should be provided to allow for independent judgments and verification of results. The case study supported this recommendation as it was necessary to include the detailed calculations as part of the procedure. Their inclusion allowed for any strengths and weaknesses in the information to be made evident, as without them, a case could not be made for requiring changes to the proposed development.

Coleman suggested that economy of data is an important consideration in an assessment methodology. Although the first investigation that is undertaken using this methodology will require substantial data collection, subsequent investigation should be able to draw from the initial data base. Also, the use of substantial amounts of data helps to ensure accuracy and objectivity. Coleman states that understandability is another key factor in that the investigation should be clear to people of divergent backgrounds. British thermal units and kilowatt hours are not commonly understood terms, and are used throughout the investigation. However, when used to compare energy consumption, the units become less important than the actual differences between consumption levels. It would not be desirable or accurate to translate these units into equivalent dollars or other energy units, as this would shift the focus of the investigation away from the energy consumption and possible savings of the development.

The reviews of environmental assessment also state that an investigation should reveal whether or not the development requires a commitment to a larger project. The case study did not have this secondary impact, but it is important that this aspect be considered, even though it requires additional data, as the provision of new energy facilities is energy consumptive. The need to utilize the state of the art in measuring energy consumption and in choosing and assessing alternatives became clear because of the different tools available for measuring energy use, and the wide variety of possible options.

Finally, the means of incorporating an energy investigation procedure into existing regulatory practices was discussed. It was determined that the procedure could be accommodated within the existing municipal and provincial planning processes in Ontario, with the possible exception of that part of the investigation which is not directed to the proponent, but to an outside agency. Some mitigation measures could not be prescribed within existing legislation, but disclosing the results of the investigation could result in voluntary changes without legislation.

In conclusion, this thesis has shown that it is feasible to develop a methodology for investigating energy use in new residential development, but there are limitations. It was established that certain elements should be included as part of an energy investigation methodology. These are: total energy use accounting to the extent possible, quantification of energy consumption and possible savings before mitigation measures are prescribed to allow for verification, and detailed descriptions of methods used for analysing energy use.

A major limitation to the methodology is that methods for predicting energy consumption are not well developed. There are currently no accurate means for examining the energy consumed for travel outside the development, and the data used to calculate transportation energy consumption within the housing development could be outdated. Most municipalities probably do not have records of the energy costs of servicing, which could further limit the use of the methodology. Only gross energy consumption data was available for energy embodied in houses. The comparison of such highly aggregated data with more accurate calculations such as those performed for the estimation of space heating energy consumption could result in an inaccurate ranking of mitigation measures. Therefore, the nature of the data that is utilized should be stated clearly. The thesis indicated that the proposed energy evaluation methodology can highlight means of using less energy or improving efficiency, but depending upon legislation of a particular jurisdiction, measures may only be partly enforceable.

The methodology allows for a continuous form of monitoring of energy-related elements that affect spatial form. The case study illustrates some minor changes in conventional development forms that could result from a greater concern for energy consumption. Innovations in conservation could give rise to further changes. As these new techniques develop, their influence on the geography of human settlements and built form could be easily identified through the application of the energy use investigation methodology.

APPENDIX 1: CALCULATIONS

A. Embodied Energy

Sanitary Sewers

Material: Clay
10" Main - Length of Each Street
6" Connectors - from Main to Middle of Lot

Total Length of Roads in subdivision: 12,438'
Avge. Length from Main to Mid-Lot: 75'
75 x 497 = 37,275'

10" Main

36 lb/ft* 8,643 Btu/lb.

36 x 12,438 = 447,768 lbs.
447,768 x 8,643 = 3.870×10^9 Btu

6" Connectors

16 lb/ft 8,643 Btu/lb.

16 x 37,275 = 596,400
596,400 x 8,643 = 5.155×10^9 Btu

$3.870 \times 10^9 + 5.155 \times 10^9$ Btu
$= 9.025 \times 10^9$ Btu Energy Embodied in Sanitary Sewers

* all energy figures from Hannon, 1977 pp. 18-20

Water Mains

Material: Clay + Copper

6" Main - Length of Each Street
3/4" connectors - Main to Mid-Lot

6" Main

16 lb/ft. 8,643 Btu/lb.

16 x 12,438 = 199,008 lbs.
199,008 x 8,643 = 1.720 x 10^9Btu

3/4" connectors (copper)

1.308 lb/ft. 73,127 Btu/lb.

1.308 x 37,275 = 48,756 lbs.
48,756 x 73,127 = 3.565 x 10^9

1.805 x 10^9 + 3.565 x 10^9 = 5.370 x 10^9Btu Energy
Embodied in Water Services

Storm Sewers

Material: Concrete

12" Main - Length of Each Street
6" Connectors - Main to Mid-Lot

12" Main

67 lb/ft. 1,782 Btu/lb.

67 x 12,438 = 833,346 lbs.
833,346 x 1,782 = 1.485 x 10^9 Btu

6" Connectors

23 lb/ft. 1,782 Btu/lb.

23 x 37,275 = 857,325 lbs.
857,325 x 1,782 = 1.527 x 10^9Btu

1,527 x 10^9 + 1.485 x 10^9 = 3.012 x 10^9Btu Energy
Embodied
in Storm Sewers

Roads

Material: Asphalt

Must Know: Length x Width x Depth

Crittendon
2,375' x 26' x 1/3' = 20,583.6 cu. ft. 27 cu. ft. = 1 cu. yd.
20,583.6/27 = 762.3 cu.yds.

Loradeen
1,325' x 26' x 1/3' = $\frac{11,483}{27}$ = 425.3 cu. yds.

Baldoon
625' x 32' x 1/3' = $\frac{6,666}{27}$ = 247 cu. yds.

Dunsfold
2,015' x 26' x 1/3' = $\frac{17,463}{27}$ = 647 cu. yds.

CrowTrail
2,875' x 32' x 1/3' = $\frac{30,666}{27}$ = 1,136 cu. yds.

McGinty
348' x 26' x 1/3' = $\frac{3,016}{27}$ = 111.7 cu. yds.

Trott
1,350' x 26' x 1/3' = $\frac{11,700}{27}$ = 433.3 cu. yds

Bradstone
1,525' x 26' x 1/3' = $\frac{13,216}{27}$ = 490 cu. yds.

Total cubic yards of Asphalt = 4,252.6
Btu/cu. yd. of Asphalt = 4,636,740
4,636,740 x 4,252.6 = 19.718 x 10^9 Btu Energy Embodied in Roads

Driveways

Material: Asphalt

10' x 45' x 1/3' = 150

150/27 = 5.6 cu. yds.

5.6 x 497 = 2,783.2

4,636,740 x 2,783.2 = 12.905 x 10^9 Btu Energy Embodied in Driveways

Sidewalks

Material: Concrete

Crittendon
$4{,}524' \times 4' \times 1/3' = \frac{6{,}032}{27} =$ 223.4 cu. yds.

Loradeen
$2{,}638' \times 4' \times 1/3' = \frac{3{,}517.3}{27} =$ 130.3 cu. yds

Baldoon
$1{,}104' \times 4' \times 1/3' = \frac{1{,}472}{27} =$ 54.5 cu. yds

Dunsfold
$4{,}321' \times 4' \times 1/3' = \frac{5{,}761.3}{27} =$ 213.4 cu. yds

Crowtrail
$4{,}146' \times 4' \times 1/3' = \underline{5{,}528} =$ 205 cu. yds.

McGinty
$696' \times 4' \times 1/3' = \frac{928}{27} =$ 34. cu. yds.

Trott
$2{,}391' \times 4' \times 1/3' = \frac{3{,}188}{27} =$ 118.1 cu. yds

Bradstone
$2{,}935' \times 4' \times 1/3' = \frac{3{,}913.3}{27} =$ 145 cu. yds.

Total cubic yards of Concrete = 1,123.7
Btu/cu. yd. of concrete = 2,594,338
1,123.7 x 2,594,338 = 2.915 x 10^9 Btu Energy Embodied in sidewalks

Summary - Buildings

Unit Type	Gross Sq. Ft.	No. Units	Btu/Sq. Ft. (Hannon)	Total Btu x 10^9
3.D.1 Type 2	1092	88	702,047	67.464
3.D.1 Type 3	984	88	702,047	60.792
3.D.2. Type 2	1092	67	702,047	51.365
4.D.2. Type 4	1275	67	702,047	59.972
3.SD.2 Type 2	1007	78	625,050	49.095
3.TH.2 Type 1	1020	109	625,050	69.493
				358.181

Summary - Servicing

	Material	Amount Required	Btu Content/Unit Btu x 10^9	Total Embodied Energy Btu x 10^9
Sidewalks	Concrete	1123.7 cu. yds	2,594.338/cu. yd.	2.915
Driveways	Asphalt	2783.2 cu yds	4,636.740/cu. yd.	12.905
Roads	Asphalt	4252.6 cu. yds	4,636.740/cu. yd.	19.718
Sanitary Sewers	Clay	1,044,168 lbs.	8.643/lb.	9.025
Watermains	Clay	199,008 lbs.	8.643/lb.	1.720
	Copper	48,756 lbs.	73.127/lb.	3.565
Storm Sewers	Concrete	1,690,671 lbs.	1.782/lb.	3.012
				52.861

B. Space Heating Information

Transmission Heat Losses

exterior area of all surfaces	measured from house plans
U coefficients of each surface	transmissivity is the inverse of resistance to heat flow(R). R values can be found in references 3 and 17.
construction type	house plans, builder
wind speed	weather stations, journals
design temperature difference	desired indoor temperature can vary, but is usually 70°F average annual minimum temperature. Can be obtained from weather stations or ASHRAE journals.
temperature of ground	ASHRAE journals, ground temperature is usually higher than air temperature in winter, so will affect design temperature difference
temperature of attic, laundry room	ASHRAE journals, temperature is usually lower than rest of house

Infiltration Heat Losses

air volume	house plans
air changes per hour	reference 29

Annual Energy Use

annual heating degree days	Ontario Building Code
furnace efficiency	reference 29

C. Space Heating Assumptions

Exterior Area of All Surfaces	measured from houseplans, listed in heat loss tables
Construction Type and U Coefficients of Each Surface	wall construction consists of: 4" face brick 1/2" cement mortar 8" concrete block R12 insulation 1/2" gypsum wallboard This construction has a U coefficient of .06, allowing for the outside surface resistance value of .17 and the inside surface R value of .68 Wood frame construction has same U coefficient: glass (double glazing, 1/4" air space) .65 doors (2" wood) .43 basement walls (concrete + R8 insulation) .18 basement floor (4" concrete) .10 ceiling (R28) .03
Wind Speed	15 mph
Design Temperature Difference	between walls and outside (70°F+-10°F) 80 between interior and attic (70°F-5°F) 65 between rec. room and ground (70°F-32°F) 38 between laundry and ground (65°F-32°F) 33 between basement floor and ground (70°F-50°F) 20
Air Volume	see heat loss tables
Air Changes/Hour	.5
Annual Heating Degree Days	6800
Furnace Efficiency	65%

D. Heat Load Calculations

Heat Loss Calculations - Peak Load
1 Storey, 3 Bedroom Detached House O.H.C. Design 3.D.1. Type 2

Surface	Exterior Area (Sq. Ft.)	U Coefficient	Design Temperature Difference	Transmission Heat Loss-Btu/hr.
Main Floor				
Walls	886	.06	80	4,253
Glass	82	.65	80	4,264
Doors	40	.43	80	1,376
Ceiling	839	.03	65	1,636
Recreation Room				
Walls	489	.18	38	3,345
Glass	8	.65	80	416
Laundry Room				
Walls	148	.18	33	879
Glass	4	.65	80	208
Floor	839	.10	20	1,678
				18,055

Heat Loss Due To Transmission = 18,055 Btu/hour

Infiltration Heat Loss: (volume x air changes x infiltration heat loss factor x design temperature difference)

Main Floor: 6,712 x .50 x .018 x 80 = 4,833 Btu/hour

18,055 + 4,833 = 22,888 Btu/hour Peak Heat Loss

Heat Loss Calculations - Peak Load
1 Storey, 3 Bedroom Détached House O.H.C. Design 3.D.1. Type 3

Surface	Exterior Area (Sq. Ft.)	U Coefficient	Design Temperature Difference	Transmission Heat Loss-Btu/hr.
Main Floor				
Walls	863	.06	80	4,142
Glass	73	.65	80	3,795
Doors	40	.43	80	1,376
Ceiling	858	.03	65	1,673
Recreation Room				
Walls	480	.18	33	2,851
Glass	8	.65	80	416
Laundry Room				
Walls	480	.18	38	3,283
Glass	8	.65	80	416
Floor	858	.10	20	1,716
				19,669

Heat Loss Due To Transmission = 19,669 Btu/hour

Infiltration Heat Loss:

Main Floor: 6,864 x .50 x .018 x 80 = 4,942 Btu/hour

19,669 + 4,942 = 24,611 Btu/hour Peak Heat Loss

Heat Loss Calculations - Peak Load
2 Storey, 3 Bedroom Detached House O.H.C. Design 3.D.2. Type 2

Surface	Exterior Area (Sq. Ft.)	U Coefficient	Design Temperature Difference	Transmission Heat Loss-Btu/hr.
2nd Floor				
Walls	660	.06	80	3,168
Glass	18	.65	80	936
Ceiling	462	.03	65	900
1st Floor				
Walls	597	.06	80	2,865
Glass	43	.65	80	2,236
Doors	40	.43	80	1,376
Recreation Room				
Walls	408	.18	38	2,791
Glass	8	.65	80	416
Laundry Room				
Walls	272	.18	33	1,616
Floor	462	.10	20	924
				17,228

Heat Loss Due To Transmission = 17,228 Btu/hour

Infiltration Heat Loss:

Main Floor: 7,392 x .50 x .018 x 80 = 5,322 Btu/hour

5,322 + 17,228 = 22,550 Btu/hour Peak Heat Loss

Heat Loss Calculations - Peak Load
2 Storey, 4 Bedroom Detached House O.H.C. Design 4.D.2. Type 4

Surface	Exterior Area (Sq. Ft.)	U Coefficient	Design Temperature Difference	Transmission Heat Loss-Btu/hr.
2nd Floor				
Walls	720	.06	80	3,456
Glass	32	.65	80	1,664
Ceiling	552	.03	65	1,076
1st Floor				
Walls	623	.06	80	2,990
Glass	55	.65	80	2,860
Doors	40	.43	80	1,376
Recreation Room				
Walls	364	.18	33	2,162
Glass	4	.65	80	208
Laundry Room				
Walls	364	.18	38	2,490
Glass	4	.65	80	208
Floor	552	.10	20	1,104
				19,594

Heat Loss Due To Transmission = 19,594 Btu/hour

Infiltration Heat Loss:

Main Floor: 8,832 x .50 x .018 x 80 = 6,359 Btu/hour

6,359 + 19,594 = 25,953 Btu/hour PEAK HEAT LOSS

Heat Loss Calculations - Peak Load
2 Storey, 3 Bedroom Semi-Detached Unit O.H.C. Design 3.SD.2. Type 2

Surface	Exterior Area (Sq. Ft.)	U Coefficient	Design Temperature Difference	Transmission Heat Loss-Btu/hr.
2nd Floor				
Walls	493	.06	80	2,367
Glass	30	.65	80	1,560
Ceiling	502	.03	65	979
1st Floor				
Walls	564	.06	80	2,707
Glass	43	.65	80	2,236
Doors	40	.43	80	1,376
Recreation Room				
Walls	484	.18	33	2,875
Glass	4	.65	80	208
Laundry Room				
Walls	172	.18	38	1,177
Glass	4	.65	80	208
Floor	502	.10	20	1,004
				16,697

Heat Loss Due To Transmission = 16,697 Btu/hour

Infiltration Heat Loss:

Main Floor: 5,796 x .50 x .018 x 80 = 4,173 Btu/hour

4,173 + 16,697 = 20,870 Btu/hour Peak Heat Loss

Heat Loss Calculations - Peak Load
2 Storey, 3 Bedroom Townhouse O.H.C. Design 3.TH.2. Type 1

Surface	Exterior Area (SQ. FT.) End Unit	Interior Unit	U Coefficient	Design Temperature Difference	Transmission Heat Loss-BTU/hr. End	Interior
2nd Floor						
Walls	501	296	.06	80	2,405	1,421
Glass	24	24	.65	80	1,248	1,248
Ceiling	512	512	.03	65	998	998
1st Floor						
Walls	442	296	.06	80	2,122	1,421
Glass	43	43	.65	80	2,236	2,236
Doors	40	40	.43	80	1,376	1,376
RecreationRoom						
Walls	452	296	.18	38	3,092	2,025
Glass	4	4	.65	80	208	208
LaundryRoom						
Walls	144	144	.18	33	855	855
Basement Floor	512	512	.10	20	1,024	1,024
					15,564	12,812

Heat Loss Due To Transmission = 15,564 Btu/hour

Infiltration Heat Loss:

Main Floor: 8,192 x .50 x .018 x 80 = 5,898 Btu/hour

5,898 + 15,564 = 21,462 Btu/hour Peak Heat Loss end units
5,898 + 12,812 = 18,710 Btu/hour Peak Heat Loss interior units

Annual Heat Loss Calculations

$$\frac{\text{Peak Heat Loss x Degree Days x 24 Hours}}{\text{Design Temperature Difference x .55 x .65}} \text{ X } .60$$

3.D.1 Type 2

$$\frac{22{,}888 \text{ x } 6{,}800 \text{ x } 24}{80 \text{ x } .55 \text{ x } .65} \text{ X } .60 = 78{,}363{,}390$$

78,363,390 x 88 (units) = 6,895,978,300 Btu/year

3.D.1 Type 3

$$\frac{24{,}611 \text{ x } 6{,}800 \text{ x } 24}{80 \text{ x } .55 \text{ x } .65} \text{ X } .60 = 84{,}262{,}554$$

84,262,554 x 88 (units) = 7,415,104,700 Btu/year

3.D.2 Type 2

$$\frac{22{,}500 \text{ x } 6{,}800 \text{ x } 24}{80 \text{ x } .55 \text{ x } .65} \text{ X } .60 = 77{,}206{,}152$$

77,206,152 x 67 (units) = 5,172,812,000 Btu/year

4.D.2 Type 4

$$\frac{25{,}953 \text{ x } 6{,}800 \text{ x } 24}{80 \text{ x } .55 \text{ x } .65} \text{ X } .60 = 88{,}857{,}264$$

88,857,264 x 67 (units) = 5,953,436,600

3.SD.2 Type 2

$$\frac{20{,}870 \text{ x } 6{,}800 \text{ x } 24}{80 \text{ x } .55 \text{ x } .65} \text{ X } .60 = 71{,}454{,}204$$

71,454,204 x 78 (units) = 5,573,427,900 Btu/year

3.TH.2 Type 1

End Units

$$\frac{21,462 \times 6,800 \times 24}{80 \times .55 \times .65} \times .60 = 73,481,082$$

73,481,082 x 22 (units) = 1,616,583,800 Btu/year

Interior Units

$$\frac{18,710 \times 6,800 \times 24}{80 \times .55 \times .65} \times .60 = 64,058,800$$

64,058,800 x 87 (units) = 5,573,115,600 Btu/year

Total For Subdivision = 38,200,495,600 Btu/year Annual Heat Loss

Summary

House Type	Peak/Unit Btu/hr	Annual/Unit Btu	Number of Units	Unit Peak Btu/hr	Unit Annual Btu
3.D.1 Type 2	22,888	78,363,390	88	2,014,144	6,895,978,300
3.D.1 Type 3	24,611	84,262,554	88	2,165,768	7,415,104,300
3.D.2 Type 2	22,550	77,206,152	67	1,510,850	5,172,812,000
4.D.2 Type 4	25,953	88,857,264	67	1,738,851	5,953,436,600
3.SD.2 Type 2	20,870	71,454,204	78	1,627,860	5,578,427,900
3.TH.2 Type 1 (end)	21,462	73,481,082	22	472,164	1,616,583,800
3.TH.2 Type 1 (interior)	18,710	64,058,800	87	1,627,720	5,573,115,600
				11,157,357	38,200,495,600

E. Energy Consumption of Indoor Lighting, Appliances, Water Heating

Appliance	Average Power Demand (Watts)	Average Annual Consumption/hld (Kwh/Year)	Subdivision (Watts)	Total (x 497) kwh/Year
Lighting	---	758		1,255,753
Refrigerator	300	994	149,100	1,646,727
Range	12,500	1,052	6,212,500	1,742,813
Color TV	330	255	164,010	422,450
Water Heater	4,500	6,000	2,236,500	2,982,000
Clothes Dryer	500	43	248,500	71,237
Clothes Dryer	4,800	413	2,385,600	684,203
Miscellaneous	---	663		
			11,248,610	8,805,183

Total Annual Consumption = 8,805,183 kwh

Total Power Demand = 11,248,610 watts

F. Energy Consumption of Street Lights

Length of streets in subdivision:	13,438 feet
Distance between lights:	125 feet
Number of lights:	100
Power demand/light:	175 watts
Total Power demand:	17,500 watts
Energy Use/light: (4,300 hrs./yr./lamp)	753 kwh/yr.
Total Energy Use:	75,300 kwh/yr.

G. Maintenance Energy Consumption

Water Supply *

435 kwh/House/yr. 435 X 497 (units) = 216,195 kwh/yr.

Sewage Treatment *

174 kwh/House/yr. 174 X 497 (units) = 86,478 kwh/yr.

Snow Removal **

12,438 feet of roads in subdivision = 2.36 miles
2.36 X 2 (trips) = 4.72 miles at 3.6 miles per gallon =
1.3 X 5 (average annual snowfalls requiring removal) =
6.5 gallons of gas/yr.

Garbage Collection **

2.36 miles at 2.3 miles per gallon =
1.03 gallons of gas for garbage collection
1.03 X 52 (weeks) = 53.56 gallons of gas/yr.

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* R. Macdonald <u>et al.</u>, 1978

** Ontario Ministry of Transportation & Communications information -- salting and sanding data not available

H. Transportation Energy Consumption Within Subdivision

Zone	Length(inches)	Number of Houses	Zone	Length(")	No. Houses
AB	2.5	6	WX	2.23	7
BC	4.0	29	XY	3.0	15
BE	2.5	21	XZ	10.25	28
CD	2.5	10	RAA	2.75	6
DE	3.75	27	AABB	2.75	20
AF	7.75	0	BBCC	2.75	12
AG	3.75	9	CCDD	2.5	19
GH	3.0	4	DDAA	2.75	9
HI	2.5	10	AEE	1.5	2
IJ	8.0	33	35zones		
JK	3.0	14			
KH	8.0	26			
GL	2.25	6			
LM	6.25	20			
MN	2.75	12			
NO	5.0	14			
LO	2.0	7			
OP	2.75	7			
PQ	7.0	21			
PR	2.75	7			
RS	5.0	18			
ST	8.0	34			
TU	2.75	10			
UV	5.25	21			
VW	2.25	7			
RW	2.75	6			

Zone	Exit	No. Houses	Route	Length Travelled	Distance Travelled By All Units	Average Distance Travelled Per Unit
				(Distance of Route No. Houses in zone)		(Total Distance No. Houses in Zone)
AB	1	6	AB	1.25	54	9
			AF	7.75		
BC	1	29	CB	2.0	355.25	12.25
			BA	2.5		
			AF	7.75		
CD	1	10	DC	1.25	155	15.5
			CB	4.0		
			BA	2.5		
			AF	7.75		
DE	1	27	DE	1.88	395.02	14.63
			EB	2.5		
			BA	2.5		
			AF	7.75		
EB	1	21	EB	1.25	241.5	11.5
			BA	2.5		
			AF	7.75		
AG	1	9	GA	1.88	86.67	9.63
			AF	7.75		
GH	1	4	HG	1.5	52	13
			GA	3.75		
			AF	7.75		
HI	1	10	IH	1.25	157.5	15.75
			HG	3.0		
			GA	3.75		
			AF	7.75		
IJ	1	33	JI	4	693	21
			IH	2.5		
			HG	3.0		
			GA	3.75		
			AF	7.75		
JK	1	14	JK	1.5	336	24
			KH	8.0		
			HG	3.0		
			GA	3.75		
			AF	7.75		

Zone	Exit	No. Houses	Route	Length Travelled	Distance Travelled By All Units	Average Distance Travelled Per Unit
KH	1	26	KH	4.0	481	18.5
			HG	3.0		
			GA	3.75		
			AF	7.75		
GL	1	6	LG	1.13	75.78	12.63
			GA	3.75		
			AF	7.75		
LM	2	20	ML	3.13	297.6	14.88
			LO	2.0		
			OP	2.75		
			PQ	7.0		
MN	2	12	MN	1.38	193.56	16.13
			NO	5.0		
			OP	2.75		
			PQ	7.0		
NO	2	14	NO	2.5	171.5	12.25
			OP	2.75		
			PQ	7.0		
LO	2	7	LO	1.0	75.25	10.75
			OP	2.75		
			PQ	7.0		
OP	2	7	OP	1.38	58.66	8.38
			PQ	7.0		
PQ	2	21	PQ	3.5	73.5	3.5
PR	2	7	RP	1.38	58.66	8.38
			PQ	7.0		
RS	2	18	SR	2.5	220.5	12.25
			RP	2.75		
			PQ	7.0		
ST	2	34	TS	4.0	637.5	18.75
			SR	5.0		
			RP	2.75		
			PQ	7.0		
TU	3	10	TU	1.38	188.8	18.88
			UV	2.75		
			VW	2.25		
			WX	2.25		
			XZ	10.25		

Zone	Exit	No. Houses	Route	Length Travelled	Distance Travelled By All Units	Average Distance Travelled Per Unit
UV	3	21	UV	1.38	338.73	16.13
			VW	2.25		
			WX	2.25		
			XZ	10.25		
RW	2	6	WR	1.38	66.78	11.13
			RP	2.75		
			PQ	7.0		
VW	3	7	VW	1.13	95.41	13.63
			WX	2.25		
			XZ	10.25		
WX	3	7	WX	1.13	79.66	11.38
			XZ	10.25		
XY	3	15	YX	1.5	176.25	11.75
			XZ	10.25		
XZ	3	28	XZ	5.13	143.64	5.13
RAA	2	6	AAR	1.38	66.78	11.13
			RP	2.75		
			PQ	7.0		
AABB	2	20	BBAA	1.38	277.6	13.88
			AAR	2.75		
			RP	2.75		
			PQ	7.0		
BBCC	2	12	CCBB	1.38	199.56	16.63
			BBAA	2.75		
			AAR	2.75		
			RP	2.75		
			PQ	7.0		
CCDD	2	19	CCDD	1.25	313.5	16.5
			DDAA	2.75		
			AAR	2.75		
			RP	2.75		
			PQ	7.0		
AEE	1	2	EEA	.75	17	8.5
			AF	7.75		
DDAA	2	9	DDAA	1.38	124.92	13.88
			AAR		2.75	
			RP		2.75	
			PQ		7.0	

Summary

A.

Average Distance = $\frac{\text{Total Distance}}{\text{Total Housing}}$

Distance travelled by all units = 6958.07 X 2 (return trip)=13,916.14
Total Housing = 497 units

13916.14/497 = 28" = 2800'

B.

Total passenger miles travelled within subdivision per household = trips/yr./hhld. x average distance travelled in subdivision x $\frac{100^{*}}{5280}$

**1280 trips/yr./hhld. x 28 x $\frac{100}{5280}$ = 679 miles travelled within subdivison per hhld/yr.

Vehicle miles per hhld/yr. = Total passenger miles per hhld/yr./occupancy factor

679/1.2+ = 566

C.

Annual gallons consumed per hhld/yr. = vehicle miles per hhld/yr./miles per gallon

566/15++ = 37.73 (per hhld per yr.)

D.

Annual gallons consumed for total subdivision

37.73 x 497 = 18,751.8

Annual energy for transportation = 18,751.8 gallons/yr.
Energy Use For
Internal Subdivision
Transportation

*to convert feet to miles **TARMS data: 1280 +1.2: TARMS data
++15 m.p.g. (Middleton)
5280' = 1 mile

I. Potential Energy Savings

Embodied Energy

Sanitary Sewers

Main

use 8" pipe * at 23 lb./ft. = 8,643 Btu/lb.

23 x 12,438 (ft. of road) 286,074

286;074 x 8,643 = 2,472,537,500
or 2.472×10^9 Btu

Proposal uses 3.870×10^9 Btu (3.870×10^9) = 1.398×10^9 Btu savings

Connector

one connector for every 2 lots*

37,275 (proposed length) ÷ 2 = 18,638

18,638 x 16 (lb./ft.) = 298,208

298,208 x 8,643 (Btu/lb.) = 2,571,411,700
or 2.571×10^9 Btu

Proposal uses 5.155×10^9 Btu (5.155×10^9) - (2.571×10^9) = 2.548×10^9 Btu savings

Asphalt

conventional driveway : 5.6 cu. yds. of asphalt
2 16" asphalt strips : 1.4 cu. yds. of asphalt
14 x 497 (units) = 695.8 cu. yds.
695.8 x 4,636,740 (Btu) = 3,226,215,800
or 3.226×10^9 Btu

Proposal uses 12.905×10^9 Btu (12.905×10^9) - (3.226×10^9 Btu) = 9.679×10^9 Btu savings

Storm Sewers

design for natural drainage : savings of 3.013×10^9 Btu

* Urban Development Standards 1976

Increased Insulation

N.R.C.C. Insulation Standards : Walls R17
Basements R9
Roof/ceiling R31.8

resulting in new U coefficients of : 1st + 2nd floor walls .05
recreation + laundry room walls .16
ceiling .027

Substituting these figures into Tables 6 - 12 =

3.D.1 Type 2

Transmission heat loss : 16,712
Peak heat loss : 21,545
Annual heat loss : 73,765,254 Btu
x 88 units : 6,491,342,300 Btu/yr. or 6.491 x 10^9

Proposal uses 6.936 x 10^9 Btu/yr. (6.936 x 10^9) - (6.491 x 10^9)= .444 x 10^9 Btu/yr. savings

3.D.1 Type 3

Transmission heat loss : 18,297
Peak heat loss : 23,239
Annual heat loss : 79,565,130
x 88 units 7,001,731,400 or 7.001 x 10^9

Proposal uses 7.415 x 10^9 Btu/yr. (7.415 x 10^9) - (7.001 x 10^9) = .413 x 10^9 Btu/yr. savings

3.D.2 Type 2

Transmission heat loss : 15,644
Peak heat loss : 20,966
Annual heat loss : 71,782,890
x 67 units : 4,809,453,600 or 4.809 x 10^9

Proposals uses 5.677 x 10^9 Btu/yr. (5.677 x 10^9) - (4.809 x 10^9) = .868 x 10^9 Btu/yr. savings

4.D.2. Type 4

Transmission heat loss : 18,193
Peak heat loss : 28,992
Annual heat loss : 84,060,552
x 67 units : 5,632,056,900 or 5.632 x 10^9
Proposal uses 6.650 x 10^9 Btu/yr. (6.650 x 10^9) - (5.632 x 10^9)
= 1.018 x 10^9 Btu/yr. savings

3.SD.2. Type 2

Transmission heat loss : 15,303
Peak heat loss : 19,476
Annual heat loss : 66,681,462
x 78 units : 520,115,400 or 5.201 x 10^9
Proposal uses 5.573 x 10^9 Btu/yr. (5.573 x 10^9) - (5.201 x 10^9)
= .372 x 10^9 Btu/yr. savings

3.TH.2. Type 1

End Unit
Transmission heat loss : 14,271
Peak heat loss : 20,169
Annual heat loss : 69,054,128
x 22 units : 1,519,191,000 or 1.519 x 10^9 Btu
Proposal uses 1.616 x 10^9 Btu/yr. (1.616 x 10^9) - (1.519 x 10^9)
= .97 x 10^9 Btu/yr. savings

Interior Unit
Transmission heat loss : 11,919
Peak heat loss : 17,817
Annual heat loss : 61,001,418
x 87 units : 5,307,123 or 5.307 x 10^9 Btu
Proposal uses 5.573 x 10^9 Btu/yr. (5.573 x 10^9) - (5.307 x 10^9)
= .265 x 10^9 Btu/yr. savings

Total savings due to increased insulation = 3.477 x 10^9 Btu/yr.

Weather Stripping and Caulking

Assume 20% reduction in infiltration (EMR Canada, 1975).[1]

3.D.1. Type 2

Infiltration heat loss: 3,866
Peak heat loss: 21,921
Annual heat loss: 75,052,596
88 units: 6,604,628,400 or 6.604 x 10^9
Proposal uses 6.936 x 10^9Btu/yr. (6.936 x 10^9) = .332 x 10^9
-(6.604 x 10^9) Btu/yr. savings

3.D.1 Type 3

Infiltration heat loss: 3,954
Peak heat loss: 23,623
Annual heat loss: 80,879,862
X 88 units: 7,117,427,800 or 7.117 x 10^9
Proposal uses 7.415 x 10^9 Btu/yr. (7.415 x 10^9) - (7.117 x 10^9) = .298 x 10^9 Btu/yr. savings

3.D.2. Type 2

Infiltration heat loss: 4,258
Peak heat loss: 21,486
Annual heat loss: 73,563,252
X 67 units: 49,287,378 or 4.928 x 10^9
Proposal uses 5.677 x 10^9 Btu/yr. (5.677 x 10^9) - (4.928 x 10^9) = .749 x 10^9 Btu/yr. savings

4.D.2 Type 4

Infiltration heat loss: 5,087
Peak heat loss: 24,681
Annual heat loss: 84,502,218
X 67 units: 5,661,648,600 or 5.661 x 10^9 Btu
Proposal uses 6.650 x 10^9 Btu/yr. (6.650 x 10^9) - (5.661 x 10^9) = .989 x 10^9 Btu/yr. savings

3.SD.2 Type 2

Infiltration heat loss: 3,338
Peak heat loss: 20,035
Annual heat loss: 68,595,354
X 78 units: 5,350,437,600 or 5.350 x 10^9 Btu
Proposal uses 5.573 x 10^9 Btu/yr. (5.573 x 10^9) - (5.350 x 10^9) = .223 x 10^9 Btu/yr. savings

3.TH.2 Type 1

End unit
Infiltration heat loss: 4,718
Peak heat loss: 20,282
Annual heat loss: 69,441,024
X 22 units: 1,527,702,500 or 1.527 x 10^9 Btu
Proposal uses: 1.616 x 10^9 Btu/yr. (1.616 x 10^9) - (1.527 x 10^9) = .89 x 10^9 Btu/yr. savings

Interior unit
Infiltration heat loss: 4,718
Peak heat loss: 17,530
Annual heat loss: 60,018,792
X 87 units: 5,221,634,900 or 5.221 x 10^9 Btu
Proposal uses 5.573 x 10^9 Btu/yr. (5.573 x 10^9) - (5.221 x 10^9) = .352 x 10^9 Btu/yr. savings

Total savings due to weatherstripping and caulking = 3.032 x 10^9 Btu/yr.

Electric Vs. Gas Furnaces

Furnace efficiences:

Electric - 100%
Gas - 65%

Annual heat loss equation becomes:

$$\frac{\text{Peak heat loss} \times \text{Degree Days} \times 24 \text{ Hours}}{\text{Design Temp. Diff.} \times .55 \times \underline{1}} \times .60$$

3.D.1. Type 2

Annual heat loss: 50,936,203
x 88 units: 4,482,385,800 or 4.482×10^9
Proposal uses: 6.936×10^9 Btu/yr. $(6.936 \times 10^9) - 4.482 \times 10^9) = 2.454 \times 10^9$ Btu/yr. savings

3.D.1. Type 3

Annual heat loss: 54,770,661
x 88 units: 4,819,818,100 or 4.819×10^9
Proposal uses: 7.415×10^9 Btu/yr. $(7.415 \times 10^9) - (4.819 \times 10^9) = 2.596 \times 10^9$ Btu/yr. savings

3.D.2. Type 2

Annual heat loss: 50,184,000
x 67 units: 3,362,328,000 or 3.362×10^9
Proposal uses: 5.677×10^9 Btu/yr. $(5.677 \times 10^9 - (3.362 \times 10^9) = 2.315 \times 10^9$ Btu/yr. savings

4.D.2. Type 4

Annual heat loss: 57,757,221
x 67 units: 3,869,733,800 or 4.869×10^9
Proposal uses: 6.650×10^9 Btu/yr. $(6.650 \times 10^9) - (4.869 \times 10^9) = 1.781 \times 10^9$ Btu/yr. savings

3.SD.2. Type 2

Annual heat loss: 46,445,236

x 78 units: 3,622,728,400 or 3.622 x 10^9

Proposal uses: 5.573 x 10^9 Btu/yr. (5.573 x 10^9) - (3.622 x 10^9) - 1.951 x 10^9 Btu/yr. savings

3.TH.2. Type 1

End Unit

Annual heat loss: 47,762,705

x 22 units: 1,050,779,500 or 1.050 x 10^9 Btu

Proposal uses: 1.616 x 10^9 Btu/yr. (1.616 x 10^9) - (1.050 x 10^9) = .566 x 10^9 Btu/yr. savings

3.TH.2. Type 1

Interior Unit

Annual heat loss: 41,638,254

x 87 units: 3,622,528,000 or 3.622 x 10^9 Btu

Proposal uses: 5.573 x 10^9 Btu/yr. (5.573 x 10^9) - (3.622 x 10^9) = 1.951 x 10^9 Btu/yr. savings

Total savings due to electric furnaces = 14.017 x 10^9 Btu/yr.

Using more efficient furnaces does not reduce heat loss, but reduces the amount of energy required to produce heat, the heat loss equation nevertheless provides an accurate indication of the level of energy savings possible.

Heat Pumps

Assume a coefficient of performance $\left(\frac{\text{kW output}}{\text{kW input}}\right)$ of 3*

Annual heat loss equation becomes:

$$\frac{\text{Peak heat loss X Degree Days X 24 hours}}{\text{Design Temp. Diff X .55 X } \underline{3}} \text{ X .60}$$

Substituting this figure =

3.D.1. Type 2

1.494×10^9 Btu/yr. heat loss

5.401×10^9 Btu/yr. savings

3.D.1. Type 3

1.606×10^9 Btu/yr. heat loss

5.809×10^9 Btu/yr. savings

3.D.2. Type 2

1.673×10^9 Btu/yr. heat loss

3.499×10^9 Btu/yr. savings

4.D.2. Type 4

1.289×10^9 Btu/yr. heat loss

4.664×10^9 Btu/yr. savings

* Middleton Associates *et al.*, "The Projected Penetration of Residential and Commercial Heat Pumps to the Year 2001," unpublished, Ontario Ministry of Energy Library, 1980, p.40

3.SD.2. Type 2

1.207×10^9 Btu/yr. heat loss

4.366×10^9 Btu/yr. savings

3.TH.2 Type 1

End Unit

$.350 \times 10^9$ Btu/yr. heat loss

1.266×10^9 Btu/yr. savings

Interior Unit

1.207×10^9 Btu/yr. heat loss

4.366×10^9 Btu/yr. savings

Total savings due to heat pumps =
28.884×10^9 Btu/yr.

Setback Thermostats

Assume that setback thermostats reduce furnace operation time to 20 hours.

Annual heat loss equation becomes:

$$\frac{\text{Peak heat loss X Degree days X 20 hours}}{\text{Design Temp. Diff. X .55 X .65}} \quad \text{x } 60$$

Substituting this figure =

3.D.1. Type 2

$5.746 \text{ X } 10^9$ Btu/yr. heat loss
$1.149 \text{ X } 10^9$ Btu/yr. savings

3.D.1. Type 3

$6.179 \text{ X } 10^9$ Btu/yr. heat loss
$1.236 \text{ X } 10^9$ Btu/yr. savings

3.D.2. Type 2

$4.311 \text{ X } 10^9$ Btu/yr. heat loss
$.861 \text{ X } 10^9$ Btu/yr. savings

4.D.2. Type 4

$4.961 \text{ X } 10^9$ Btu/yr. heat loss
$.992 \text{ X } 10^9$ Btu/yr. savings

3.SD.2. Type 2

$4.644 \text{ X } 10^9$ Btu/yr. heat loss
$.929 \text{ X } 10^9$ Btu/yr. savings

3.TH.2. Type 1

End Unit

1.347×10^9 Btu/yr. heat loss

$.269 \times 10^9$ Btu/yr. savings

Interior Unit

4.644×10^9 Btu/yr. heat loss

$.929 \times 10^9$ Btu/yr. savings

Total savings due to setback thermostats =
6.365×10^9 Btu/yr.

Lighting

Room Lighting

Energy Use With Incandescent Lighting: 376,726 kwh/yr

Energy Use With Fluorescent Lighting (-5): 75,345 kwh/yr

Savings: 301,381 kwh/yr

Street Lighting

Energy Use With Mercury Vapour Lighting: 17,500 watts

75,250 kwh

Energy Use With High Pressure Sodium Lighting: 10,000 watts

43,000 kwh

Savings: 7,500 watts

32,250 kwh

Water Heating

Solar Water Heaters

Reduce requirements of a Conventional Water Heater by 70%

Energy Use with Conventional Electric Water Heater:

2,236,500 Watts 2,982,000 kwh annually

Energy Use with Solar Water Heater Assist :

670,950 Watts 894,600 kwh annually

Savings :

1,565,550 Watts 2,087,400 kwh annually

Restricted Flow Faucet Fittings

Reduce Hot Water Use by 15%

Conventional Hot Water Use:		2,236,500 Watts	2,982,000 kwh/yr
Restricted Flow	:	1,901,025 Watts	2,534,700 kwh/yr
Savings	:	335,475 Watts	447,300 kwh/yr

Solar Water Heater and Restricted Flow Fittings: 1,901,025 Watts
savings

Savings: 2,534,700 kwh/year

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