RM-78-68

RESIDENTIAL ENERGY USE MODEL FOR AUSTRIA (REUMA)

Erwin Pönitz

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PREFACE

In January 1975, IIASA initiated a research program designed to integrate regional energy and environmental management from a systems perspective. Regional as used here, is not limited to subnational or multi-nation areas; rather it refers to a geographic region, appropriately bounded so that it is possible to speak of energy and environmental systems, either from a physical, socio-economic, or administrative perspective, or from all three. A *regional* rather than *global* perspective has been employed because many of the significant social and environmental consequences of energy systems are best analysed within the context of a specific region. This study, housed within IIASA's Resources and Environment Area, complements IIASA's ongoing Energy Systems Program which focuses primarily on global aspects of energy.

Four main regional case studies have been carried out within the framework of the study. The work originated at the University of Wisconsin-Madison with a policy-oriented study of energy systems in the State of Wisconsin, USA. It was extended within a comparative framework at IIASA to include the German Democratic Republic, Rhone-Alpes (France), and Wisconsin. The most recent study has been of Austria. The research has been directed both toward methods and policy analysis, in an effort to bridge the gap between the practitioner and the client of applied systems analysis.

In the process of describing and disseminating the results of this research, IIASA has become aware of the breadth of interest and expertise of our audience. For example, some individuals are interested in mathematical details, computer software data requirements, etc., whereas others seek only the policy implications of the results. With these broad interests in mind, we have structured our reporting to meet the needs of four audience groups:

1 Policy- and Decision-makers

2 Energy/Environment managers, planners, and technical advisors

3 Modellers and analysts

4 Computer systems specialists and programmers.

This report is addressed primarily to groups 3 and 4 above. It describes a residential end-use energy model for Austria. Although this paper explicitly describes the model version operable at IIASA and applied to the Austrian case study, it also provides a general approach for analysing the residential sector in a variety of regions. A detailed listing of this model, data bases, parameter description, and a sample run are available in the form of an internal IIASA Working Paper (WP - 78 - 60, IIASA). In addition, through an interinstitutional cooperation, the model has been transferred to the computer facilities of the Verbundgesellschaft (the Austrian Electric Utility Association).

Two additional IIASA documents related to this report are:

Foell, W.K. et.al., Assessment of Alternative Energy/Environment Futures for Austria: 1977 - 2015, RR-79-00, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1979, forthcoming.
This report provides a description of the IIASA policy-oriented case study of Austria;

Foell, W.K., et. al. A Family of Models for Regional Energy/Environment Analysis, (forthcoming), International Institute for Applied Systems Analysis, Laxenburg, Austria, 1979
This report provides an overview of the approach and the models used in the regional case studies.

Other previous IIASA publications from the project are listed at the end of the report.

W.K Foell
December, 1978

RESIDENTIAL ENERGY USE MODEL FOR AUSTRIA (REUMA)

ABSTRACT

The residential energy use model is a computer simulation model, which calculates the annual end use energy demand for the residential sector Any simulation period up to 50 years can be chosen. The model is structured around the housing stock and its components of change, which are annual construction, demolition and retrofitting. The model is linked to a population model which provides, as a major driving function, the number of households for each simulation year. Energy use for space and water heating is calculated for seven energy types by using parameters such as floorspace, heat loss, heating hours, hot water demand and appliance efficiency. Energy demand from fourteen other appliances is calculated from the fraction of households owning each appliance and the average energy use per appliance. The housing stock is broken down into twelve home types and the parameters mentioned above reflect the characteristics of each home type.

Census data are used as an initial reference point. Alternative scenarios can be created with differing assumptions concerning future technological, economic, environmental and lifestyle changes so that a variety of alternative futures may be analysed.

ACKNOWLEDGEMENTS

The author is indebted to several individuals for their aid in carrying out this research. I would like to thank especially Loretta Hervey (IIASA) for providing valuable assistance in the editing process and Alois Hoelzl (IIASA) for writing the program to simulate fuel substitution processes. I would also like to thank Helen Maidment for her helpful comments on an earlier draft of this paper. A special note of gratitude goes to Anton Toifelhardt for his contribution in getting REUMA running. Finally, I am indebted to Jackie Buehring, Robin Dennis and W.K. Foell for making helpful comments on the last draft of this paper.

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Introduction

Between the end of World War II and the early 1970's, residential energy use in Austria grew steadily due to growth in population, households, income, and the relative decline in retail fuel prices. Energy consuming household devices were introduced on a broad scale. At present residential end-use energy accounts for approximately 22% percent of total end use energy in Austria. [1]

During the past few years, however, a number of forces have emerged that may significantly alter historical trends. Residential fuel prices have begun to increase and in addition to the economic pressure of rising prices, a number of institutional efforts to reduce residential energy consumption have been started on various levels.

The Residential Energy Use Model for Austria (REUMA) provides a systematic framework for analysis of residential energy consumption based upon physical characteristics and a high degree of disaggregation of the housing stock. REUMA provides the means to answer many specific energy questions that decision makers are concerned with.

The first version of the residential model was developed at the University of Wisconsin [2]. The model has been extended and generalized at IIASA [3] for use in an Energy/Environment study on Austria [4]. Although this paper explicitly describes the version operable at IIASA and applied to the Austrian case study, it provides a general description of how the residential sector can be analysed in a variety of regions.

In section 1 of this report possible approaches to the simulation of residential energy demand are discussed. In section 2 the purpose of the model and its adaption for alternative futures is described. In section 3 the general structure of the model, assumptions, scenario results, flow diagrams, functional relationships, and limitations are explained. In section 4 sensitivity studies concerning improved insulation and application of solar heat are considered in detail. In section 5 aggregated result for one scenario are presented.

A Working Paper will be published in connection with this report (IIASA, WP-78-60, Residential Energy Use Model for Austria - REUMA). It includes:

- A block diagram of the model, the principle flow diagrams;
- A description of the general approach used to specify fuel substitutions;
- Input-, output-, and workfiles; A list of all subroutines, their function, usage, and the other subroutines they call; A listing of the program, with subroutines in alphabetical order;
- An alphabetical list of all parameters used in the model, and a comprehensive parameter description;
- An example of the data input file "rdatabase", and a sample run.

1 Types of Residential Energy Use Models

Various methods can be applied for the projection of residential energy use. In general, they can be classified as either engineering type models, economic type models or engineering - economic type models.

Engineering Type Models

This type of approach relies on physical, quantifiable characteristics, such as the number of homes, their age, thermal integrity, the kind of fuels used, heating degree days, etc., and some kind of population projection. On the basis of this input, demolition and construction of homes is simulated. The housing stock is usually broken down into home types (e.g. single family homes, apartments) and the fraction of homes owning each appliance and the average energy use per appliance are multiplied by the number of homes to derive the energy consumption by energy type.

Behavioral characteristics are represented to a lesser degree in these type of models. Trends toward certain kinds of energy or certain types of appliances are exogenously determined by the user of the model on the basis of time series analysis and best guesses about future energy prices and availability.

The advantage of this type of model is its basic simplicity. Structure and results can be easily conveyed to differing clients and the general public. It is useful to evaluate engineering projects which are based on single housing units, e. g. large scale retrofitting programs, since the model keeps track of the number and age of homes and the number of appliances. This feature makes it also possible to become aware of time lags for replacing outworn equipment or retrofitting a large housing stock. The model represented in this paper is a engineering type model.

The limitation of engineering type models is the absence of explicit economic parameters, such as consumer responses to price or income changes with regard to energy consumption patterns.

Economic Type Models

Economic approaches attempt to explain energy consumption of a certain fuel as a function of parameters such as real disposable income, temperature coefficients, demand and price of the fuel. The method employed is an empirical investigation of time series and the calculation of correlation coefficients [5]. Price, income elasticities, and cross elasticities are calculated. This approach has limitations for medium to long term model simulations because it treats future consumption in terms of historical time series, when scarcity of energy and environmental considerations were not important issues. Technical components of energy consumption i.e. constraints of materials and time lags are not treated. It can be argued that with the expected scarcity of resources an optimal societal use of energy is required and that a regulating force other than mere price signals could be introduced to encourage consumers to save energy (e. g. energy consumption in well-insulated buildings is remarkably lower and does not involve change in the relationship between the price of fuel and income).

When considering the micro-economic approach to the problem of energy use, one has to take into account that the market price of energy hardly reflects the costs, benefits and the scarcity of energy resources such as oil and natural gas. Differing prices for a given energy type, e. g. higher prices for peak demand of electricity or large users are difficult to treat.

Engineering-Economic Type Models

The engineering-economic type of models attemts to combine the merits of the engineering and economic approaches. An example of this type of model is a comprehensive engineering-economic computer simulation model developed by E. Hirst et al. [6]. The model consists of three components. The first estimates stocks of occupied housing units by type. The second component is the elasticity estimator; this program calculates price and income elasticities of three major household fuels (electricity, gas and oil) for each of six end uses (space heating, water heating, refrigeration, cooking, air conditioning and other). The third component of the model is called engineering cost and includes energy use for new equipment and thermal integrity of new structures. At present the model is hampered by the fact that there exists no statistical evidence for the assumed price and income elasticities.

2 Purpose of the Model

The purpose of REUMA is twofold:

(1) REUMA belongs to the category of "engineering" models. It calculates the annual end use energy demand for the residential sector on the basis of population data, the number of occupied housing units and physical parameters such as home size, energy use, insulation standards, appliance ownership and use, etc. This output is available at many levels of disaggregation. The model can also provide input for environmental models, energy supply models or other further analyses.

No quantitative statistical relationship between GNP and the variables has been established. We have used judgement rather than an explicit econometric approach to relate growth of GNP to consumption pattern in the residential sector.

(2) The model can be used to assess the consequences of proposed measures or to analyse trends in the residential sector. This can be done by simulating different policies concerning home construction, retrofitting of existing homes, blend of appliances, and type of fuel used. In this manner, the model becomes a tool for analyzing a variety of

alternative futures (scenarios). For example, it can be used to evaluate the impact of energy conservation measures as a guide for action and also for planning of future research.

Typical questions which the model treats are:

- How could the demand for electricity, gas, oil, coal, wood, and district heat develop in the future?
- What savings could be achieved if: a) NEW HOMES were better insulated in the future? b) Homes were retrofitted to reduce heat losses?
- What role could alternative technologies play in the future, if solar energy or heat pumps were introduced, for example, on a broad scale?
- What impact upon energy consumption could be achieved by improving the efficiency of space heating systems?
- What impact will larger NEW HOMES have upon energy consumption?

2.1 Adaption of REUMA for Alternative Futures (Scenario) Analysis

There are considerable uncertainties involved in evaluating future trends and developments in residential energy consumption. The approach used in this research is simulation modeling based upon alternative futures (scenarios).

Simulation has been chosen as approach for several reasons: a) The approach permits evaluation of alternative sets of assumptions regarding future developments of the residential sector; b) the choice of output from simulation models is very flexible, i.e. it can be produced in various levels of disaggregation and in terms of numerous sets of parameters, and c) a simulation approach can handle uncertainties by means of sensitivity studies [7].

"Scenarios" are hypothetical sequences of events constructed for the purpose of focusing attention on causal processes and decision points [8]. In more explicit terms, the primary objectives of scenario writing are: (1) To describe the sensitivity of energy usage to socio-economic, technological, and life-style changes. (2) To describe and analyse the consequences of a specific energy policy option on the residential sector. (3) To provide a consistent set of assumptions.

One can also perform sensitivity studies on the basis of a given scenario; such studies permit the evaluation of the effects of variations in one policy variable, while others are held constant.

Because REUMA was built for scenario analysis, it has been highly parameterised. Thus it is possible for the user of REUMA to create systematically and exogenously a large number of "alternative futures", a process which is commonly referred to as scenario writing. "The greatest value of writing these alternative futures may be their catalytic contribution toward stretching the imagination and inducing fresh thinking. It must be stressed that these futures should in no way be considered as forecasts". [9]

Three major aspects of REUMA must be distinguished:

- (1) The bookkeeping system in REUMA, which is a simple algorithmic description of how the model keeps track of stocks and flows of homes and appliances.
- (2) Initial input data, i.e. current information about the residential sector in a specified region such as the number of inhabited housing units, and the ratio of single family homes to apartments, and
- (3) scenario assumptions about the direction and strength of future trends.

A flow diagram which shows the distinction between the bookkeeping system and scenario assumptions is presented in Figure 1.

In order to better explain and illustrate the use of REUMA one scenario for Austria has been used in this report to provide examples of computations. It may be briefly described as follows:

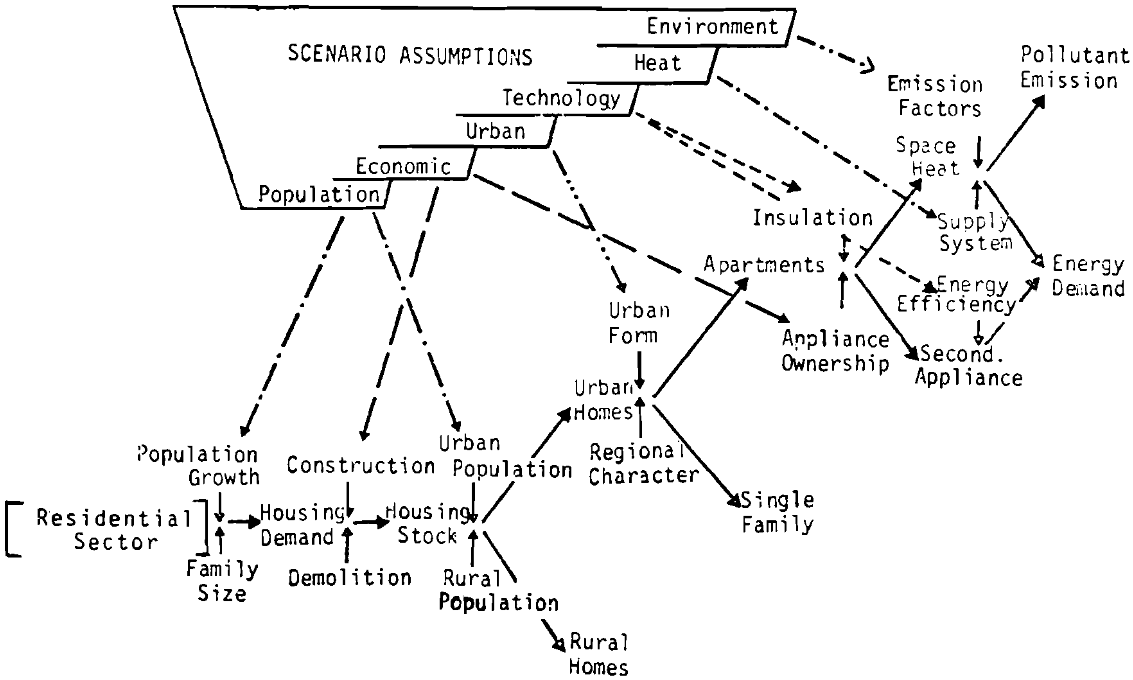

Figure 1 Representation of the Interaction Between a Scenario and REUMA

2.2 Conservation Scenario

REUMA was developed in conjunction with the IIASA study on Regional Energy/Environment Futures for Austria 1978 - 2015 [1]. In this study a conservation scenario was written in order to evaluate impact of such a policy on the industrial, transportation, services, agriculture and residential sectors. The set of assumptions underlying this scenario is used to investigate how energy use can be lowered by strict conservation policies.

In this scenario the growth of floor-space per capita in the residential sector is assumed to be moderate, and large improvements in insulation and efficiency standards are assumed. The fraction of households owning each type of household appliance is assumed to saturate at moderate level and speed. A sensitivity study examining penetration of alternative energy type technologies has been carried out on the basis of this scenario. Results of the Conservation

Scenario developed for the Austrian residential sector are used to illustrate the use of REUMA

2.3 Examples of Input and Output

The following major inputs have to be provided to define alternative residential energy use futures.

Inputs for the Projection of the Number and Type of Occupied Housing Units:

- Population; family size; development of population and family size in urban and rural areas;
- the number of inhabited single family homes and apartments in the starting year;
- homes grouped according to age for the starting year for the demolition subroutine;
- preference to construct NEW HOMES as single family homes or apartments in urban and rural areas.

Inputs to Calculate Energy Consumption for Space and Water Heating:

- Average floor area per home type and construction trends with regard to floor area over the scenario time frame (life style);
- energy mix and base appliance [1] mix used for space and water heating; specification of shifts in energy types and base appliances for the simulation period in the form of transition matrices;
- heating patterns, (i.e. amount of floor-space heated);[2]

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1 In this report appliances for space and water heating are called base appliances.

2 Heating patterns are closely related to type of energy type and base appliance, i.e. people living in homes

- average yearly heat loss per square meter per hour;
- average heating degree hours per year;
- average efficiencies for base appliances;
- technological changes, including efficiencies of equipment and thermal integrity of homes;
- life style, including attitudes towards energy use for space and water heating;
- use of unconventional energy sources.

Inputs to Calculate Energy Consumption for Secondary Appliances:

- Development of population and family size;
- starting and saturation fractions for secondary appliances;
- the time period until the difference between the saturation fraction and the starting fraction are halved;
- average energy consumption per appliance per home;
- technological changes, including efficiencies of equipment.

By various combinations of scenario input variables a great number of alternative futures can be created.

Outputs of the Model:

- The number of families; annual number of NEW HOMES, of demolished homes; the number of single family homes and apartments; the age structure of the housing stock;

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fitted with single ovens utilising coal or wood tend to heat only one room.

- average floor space of homes according to home type and age;
- percent of homes using each energy type;
- energy use by energy type;
- total energy use for space, water heating and household appliances;
- cumulative energy use over the simulation period;
- energy use per capita and per household;
- use of alternative energy types.

Figure 2 shows a typical output for the Austrian conservation scenario; here the change in the use of seven energy types over the time frame of of the scenario is presented. The model contains a great number of variables, which show energy use at different levels of disaggregation.

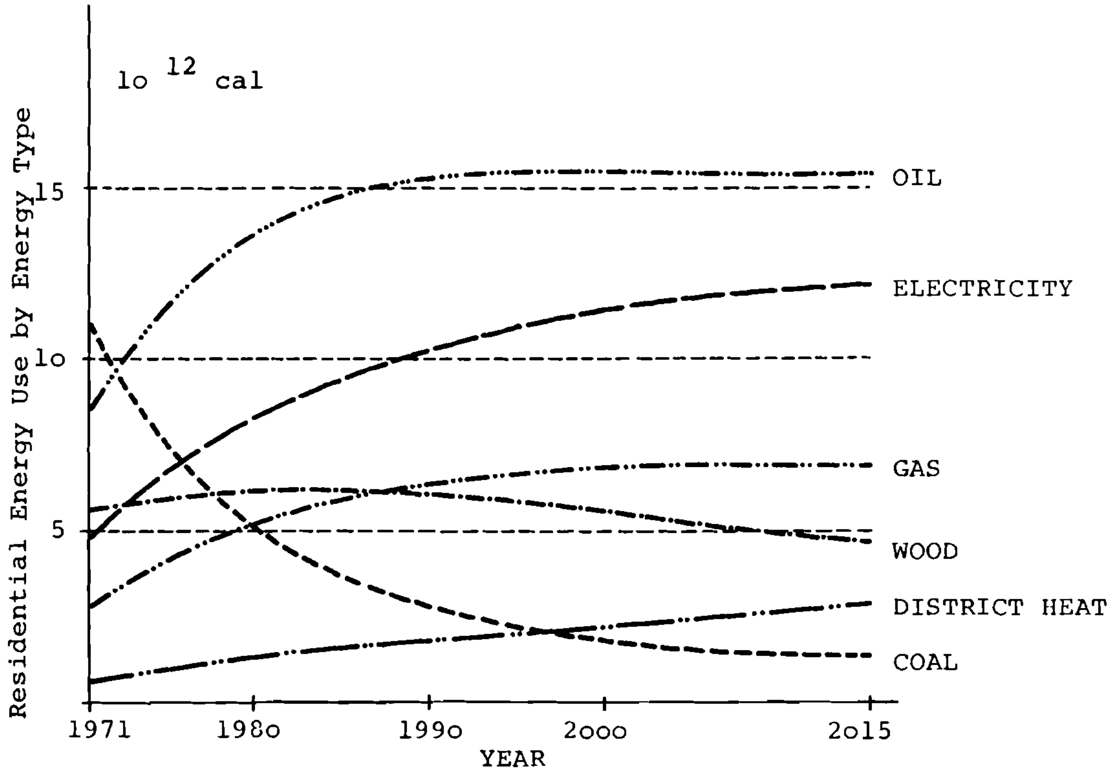

Figure 2 Energy Demand by Energy Type for the Austrian Conservation Scenario

3 General Structure of the Model

This section describes the major structures and subroutines of the residential energy use model. The most important definitions, assumptions, limitations, basic equations and flow diagrams of these major subroutines will be discussed in turn below.

The subroutines of the residential model are built around the following major issues:

- Population Trends

  In the Austrian Energy/Environment Study this information was provided exogenously by a Population Allocation Model (see section 3.1 of this report).

- Disaggregation of the Housing Stock:

  On the basis of the number of urban and rural families, the number of single family homes and apartments, and the time of construction, twelve home types are distinguished. These reflect the variety of the housing stock and different construction policies for different home types with respect to energy types, base appliance types, home size, etc.

- Changes in the Housing Stock:

  Several subroutines interface here. These are the INCREMENTAL HOMES [3] subroutine which calculates the number of homes needed because of increases in the number of families and the REPLACEMENT HOMES subroutine which calculates the number of homes needed in place of demolished homes. These two subroutines are driven by the number of new families formed per year and the annual rate of demolition These two categories of homes together form the category of NEW HOMES, which is the number of homes constructed in a given simulation year. Another subroutine keeps track of the number of single family homes and apartments and their construction years for the age dependent demolition subroutine. In REUMA a distinction is also made between homes constructed before the starting year of the model (OLD HOMES) and homes, which are constructed between the starting year and a given simulation year of REUMA (TOTAL NEW HOMES).

- Energy Types, Heating Appliances and Substitution Processes:

  In the model matrices have been used to describe probabilities of energy type and heating appliance use for various home types. Three base appliance types (single oven heating, central heating and water heating) and up to seven energy types are considered. A set of subroutines has been built for the manipulation of these matrices, in order to simulate retrofit of homes and changing construction policies. The use of alternative energy sources can also

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3 In this report the terms "home" and "housing unit" are used interchangeably.

be analysed.

- Energy Demand Life Style and Technologies of Energy Use:

  A set of subroutines calculates energy demand for space heating, water heating and for household appliance use. Parameters reflecting life style such as home size and heating habits are exogenously determined by the user of the model. Applied technologies are reflected by parameters such as heat losses and efficiencies of appliances. The use of alternative energy technologies such as solar power is considered in a seperate subroutine (section 3.5.3).

  The household appliance subroutine calculates ownership fractions for 14 different household appliances. Input data determine starting and saturation values, saturation speed, and consumption levels for each appliance.

In Figure 3 the structure of the model is shown in a simplified manner:

- A major driving force is the population model, which provides the number of families;

- INCREMENTAL HOMES needed for new families each year are one component of the number of NEW HOMES in a given simulation year;

- REPLACEMENT HOMES are needed to substitute demolished homes each year;

- the construction policies apply to NEW HOMES (=construction in a given simulation year) and are a major area where influence can be exerted upon future residential energy consumption patterns;

- the "housing population model" keeps track of the age of homes. It is needed to simulate age dependent demolition of homes and to reflect different characteristics and/or policies for homes in connection with their age;

- retrofitting policy options are needed, first because retrofitting occurs in the real world, second, in order to be able to simulate rapid changes concerning the entire housing stock. Because the number of NEW HOMES is small

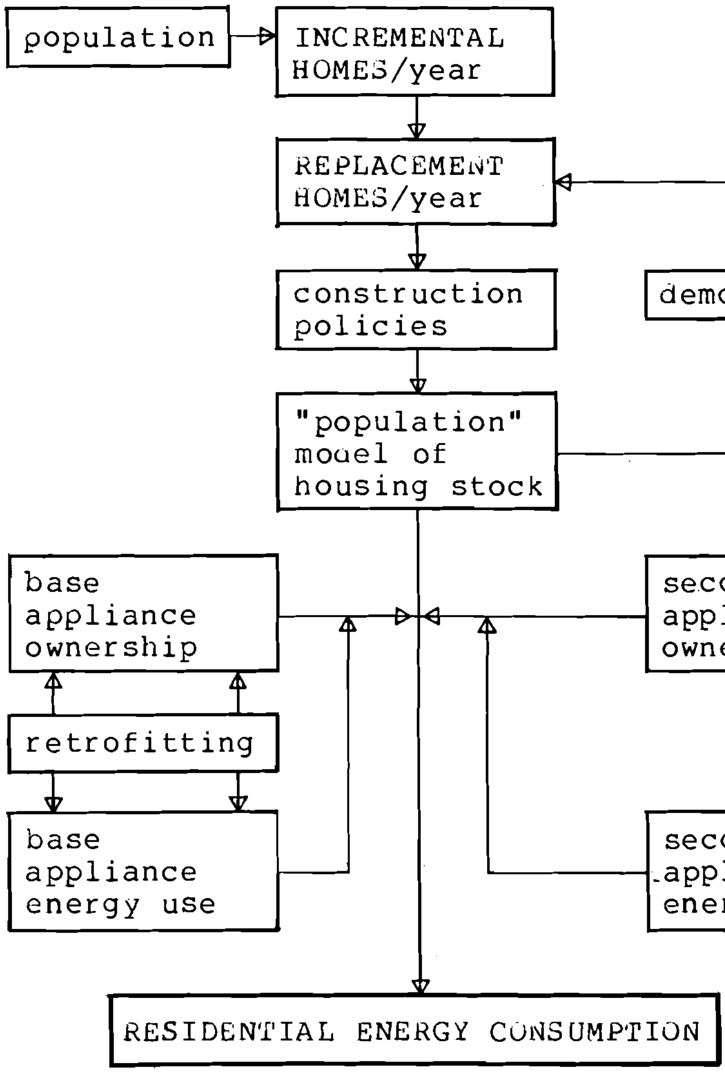

Figure 3 Flow Diagram - General Structure of REUMA

compared to the total housing stock, significant time lags would have to be expected before energy conservation policies concentrating solely on NEW HOMES take effect;

- it is necessary to separate base appliances (which are appliances for space and water heating) from secondary or household appliances. The reason lies in the different magnitude of their respective energy consumption, the different energy types used and the different patterns of acquiring and changing them (a central heating system which is an integrated part of a home vs. buying a refrigerator).

The model links population, homes, demolition, REPLACEMENT HOMES, INCREMENTAL HOMES, NEW HOMES, appliances and energy use. The initial input data for a specified region and for a specified year in the recent past marks the starting year of the model calculations. When the model departs from the present (i. e. the time for which census data is available) during its simulation time frame, alternative consistent sets of assumptions (scenarios) underlie the model calculations.

In Figure 4 a more detailed flow diagram of REUMA is presented. It shows how the the major structures and subroutines of the residential energy use model interact. These subroutines and model components are discussed in more detail in the following section.

3.1 Population Model Input

REUMA requires on an annual basis the following regional data:

- Population and annual increments;
- number of households and annual increments.

Assumptions

The number of households is calculated using assumptions about average household size development.

For Austria it was assumed that the average household size would decrease at a rate of 3% per year in each district. This value is taken from a projection of the average household size in Austria to the year 2000 made by the Austrian Central Statistical Office (Oesterreichisches Statistisches Zentralamt). [10]

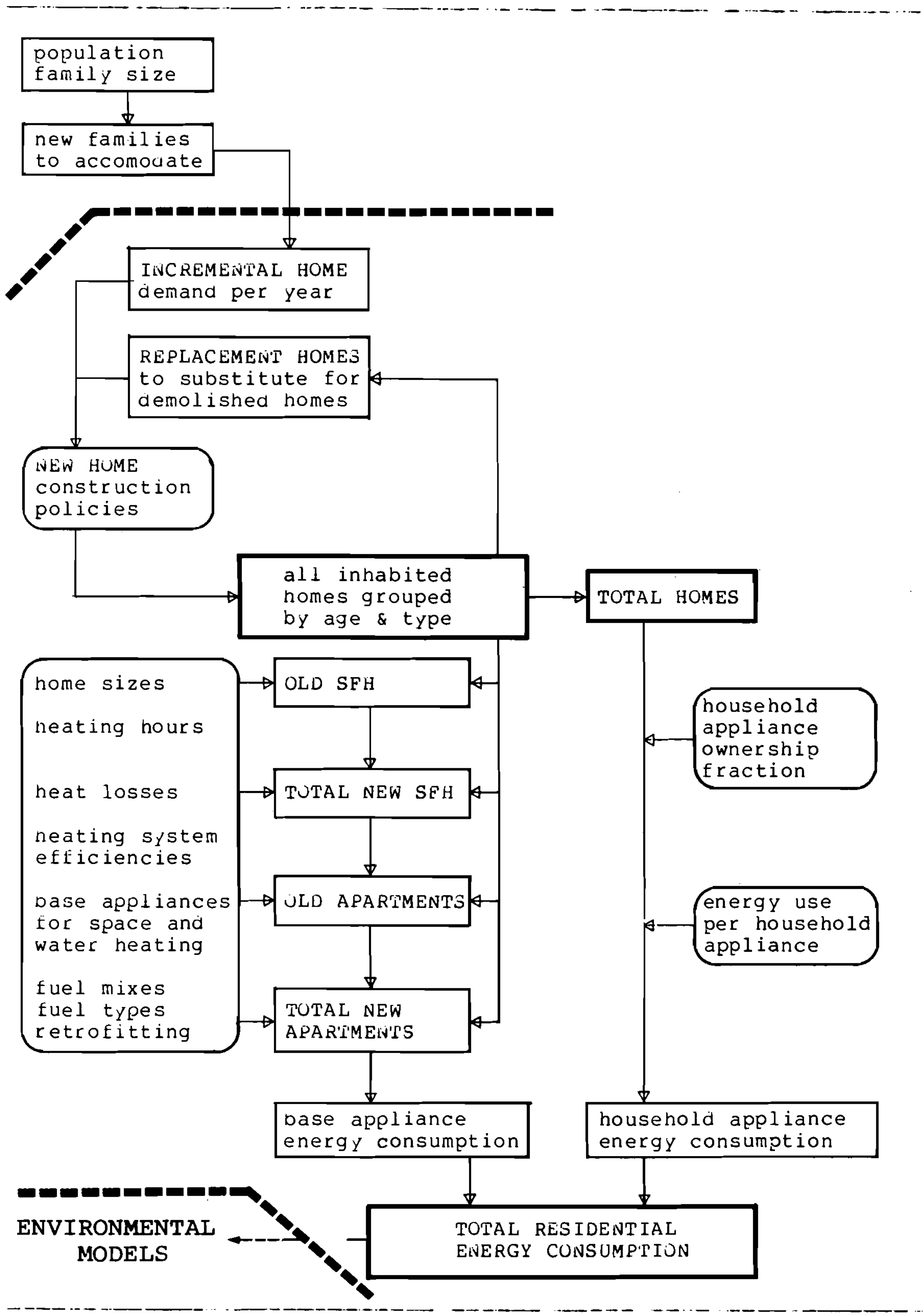

Figure 4 Flow Diagram - Flow of Information in the Residential Energy Use Model

Current population, annual increments in population, the current number of families, and annual additions to the number families are required for both urban and rural areas of a region. For this purpose a Population Allocation Model was built [3], which allocates the population and population increments to the urban and rural categories. The distinction between urban and rural areas is necessary for Austria, because the two areas have significantly different characteristics with respect to factors that affect energy consumption, such as average family size, type and size of homes, equipment of homes, and the energy types used, [4] etc. Drawing a boundary between urban and rural areas presents some difficulty. The distinction between urban and rural areas depends very much upon the purpose of the study and the available statistical data. In the Austrian study, community size has been assumed to be the relevant variable reflecting urban and rural characteristics; this in turn is based on the relationship between the agricultural population and community size. [11]

An analysis of the relation between community size and the fraction of the population dependent on agriculture (Agrarquote) in 1971 showed that a community size of 3000 is a good approximation of the dividing point between communities with less and with more than 10% agricultural population. This is in turn a reasonable dividing point between communities with a heavy reliance on wood on one hand, and on the other hand of communities using mainly oil and gas (and to some extent coal) for space heating. Because of the many area redefinitions in Austria in the recent past and the resulting arbitrariness in choosing the community size in a particular year to distinguish between rural and urban areas, the approximation can be considered satisfactory. [5]

By setting parameters in the population allocation model, it is possible to examine population shifts to rural areas and decline of urban areas and vice versa.

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4 As a contrast, people in Wisconsin, USA, use natural gas in urban areas and bottled natural gas in rural areas; in such a case a distinction between urban and rural areas could be bypassed.

5 As shown in Figure 10 on Page 39.

Scenario Results

The 1971 population of Austria was 7.46 million, and the OeIR (Oesterreichisches Institut fuer Raumplanung) projection (Variante 2.1) for 1991 is 7.69 million [12]. Interpolation and extrapolation result in population estimates of 7.66 million in 1990, 7.90 million in 2000, and 8.26 million in 2015 [13]. This projection seems high in the light of current child-bearing patterns. A more recent OeIR projection (Variante 4.3) takes into account the decrease of the fertility rates observed during the last few years. The resulting population projection for 1991 is 7.34 million. Applying the same inter- and extrapolation procedure as in the case of Variante 2.1, one obtains population estimates of 7.35 million in 1990, 7.30 million in 2000, and 7.24 million in 2015. This value is 13% lower than the value given in Variante 2.1, which has been used for the conservation scenario in this paper.

The residential energy demand projections would be lower if one uses lower population projections. Figure 5 shows both historical population data and the estimates used in conservation scenario. A shift to urban areas has been assumed. The rural population calculated by the population allocation model for the Variante 2.1 accounts for 39% of the total in 1971, 36% in 1990, 35% in 2000, and 33% in 2015. The fraction of rural homes is 32% in 1971, 30% in 1990, 29% in 2000, and 27% in 2015.

3.2 Disaggregation of the Housing Stock into Home Types

Great differences between the energy consumption of various home types (i.e. single family vs. apartments and rural vs. urban homes) can be observed. In order to capture these differences, the housing stock has been broken down into twelve subgroups of homes. In forming these subgroups, the size of the building the home is located in, the time of construction and the location have been taken into consideration.

1) Size

Since multifamily dwellings (especially high-rise buildings) have a smaller number of exposed surfaces, smaller window area, and often a smaller floor area, the heat losses per dwelling are considerably lower than for detached single family homes with similar insulation.

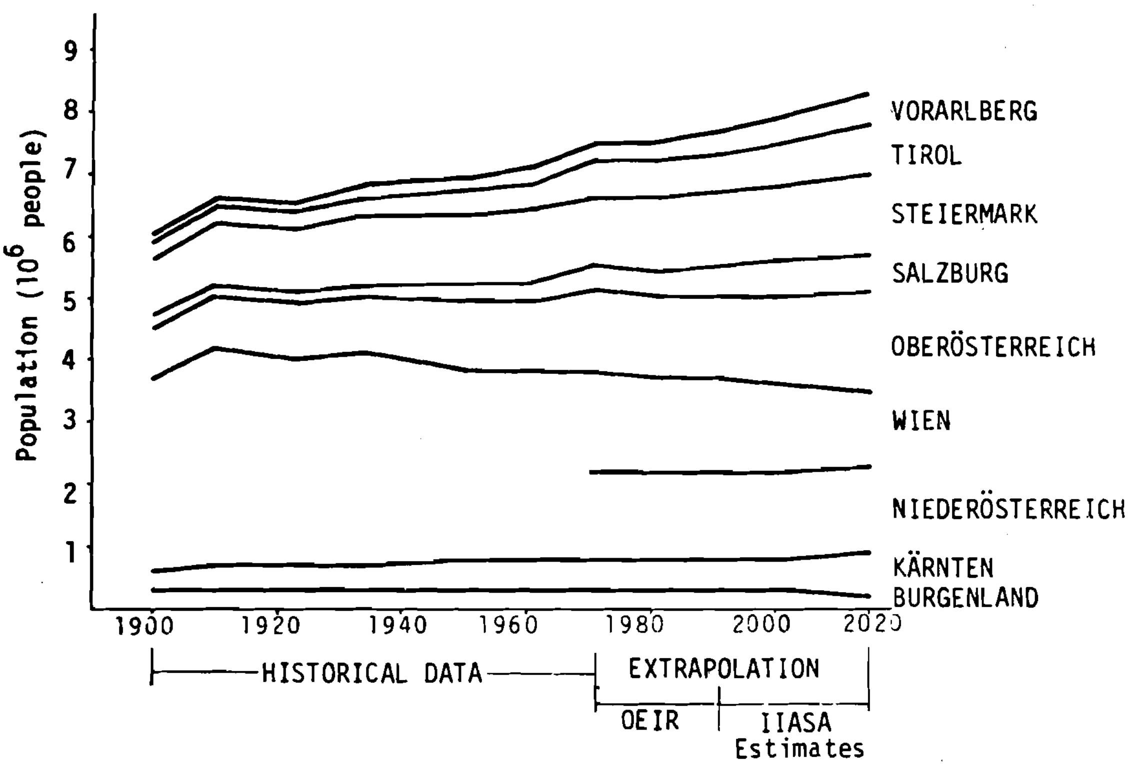

Figure 5 Population - Historical Data and Scenario Assumptions

Austrian building censuses distinguish between two major groups of dwelling units (based upon building size) and this disaggregation has been used in REUMA: (1) a single family home is located in a building containing no more than two homes. In 1971 44% of the inhabited homes consisted of single family homes [14]. (2) an apartment is located in a building containing three or more homes. Significant differences can be observed between the heating modes and energy types used in these two groups.

2) Time of Construction

In REUMA three categories of homes are distinguished according to the time of construction:

1 All single family homes and apartments constructed before the starting year of REUMA are lumped together as OLD SINGLE FAMILY HOMES/APARTMENTS and distinguished from

2 TOTAL NEW SINGLE FAMILY HOMES/APARTMENTS which are constructed in any given year after the starting year of simulation.

3 Annual construction of homes has two components:

3a) INCREMENTAL SINGLE FAMILY HOMES and APARTMENTS are needed to house new families;

3b) REPLACEMENT HOMES (single family homes/apartments) are needed to substitute for demolished homes.

INCREMENTAL HOMES plus REPLACEMENT HOMES constructed in a given simulation year are called NEW HOMES. These homes are built according to construction policies, which vary over time and reflect changes in lifestyle and technologies according to scenario assumptions.

In Austria, major differences between OLD (pre-starting year) and NEW HOMES can be observed with respect to their base appliances and energy types used, as shown in Figure 11 on page 43.

REUMA adds up NEW HOMES homes over the simulation time frame to obtain TOTAL NEW HOMES. The variables reflecting the energy types, base appliances, home size, insulation levels, and hot water consumption of TOTAL NEW HOMES as a whole are the weighted averages of the characteristics of NEW HOMES built each year, e.g. the floorspace of apartments built in the starting year of the model was assumed to be 67 square meters in the case of Austria; over the time frame of the scenario the floorspace of NEW APARTMENTS was assumed to increase on a stepwise basis to 80 square meters in the year 2000 and to maintain this level until 2015. The weighted average of the size of TOTAL NEW APARTMENTS constructed during the 45 year period is 75.9 square meters.

The disaggregation into an OLD (= pre-starting year), NEW (= annually constructed), and TOTAL NEW (= post-starting year) components of the housing stock is useful

- to reflect different probabilities for space and water heating appliances and energy types used,
- to show the relative weight of stocks and flows of homes and to examine time lags,

- to simulate the different degree of influence that can be exerted on existing homes compared to those which have yet to be constructed; (eg. retrofitting of old homes vs. changing construction policies for NEW HOMES built in a given simulation year).

Though some or all of the "older" homes in bad condition can be demolished, there is a possibility in the model to simulate retrofitting. In this context, retrofitting refers to changes in base appliances and/or energy types, and the reduction of average annual heat losses through improved insulation. (This is discussed in more detail in sections 3.4.1 and 3.5.2.)

TOTAL NEW HOMES are not assumed to be retrofitted with different base appliances and energy types during the simulation period of REUMA . However, it is possible to simulate reductions or increases in the heat losses of TOTAL NEW HOMES, in order to examine the consequences of improving the insulation of these homes or permitting insulation materials to decay. [6]

3) Location

OLD, TOTAL NEW, and NEW SINGLE FAMILY HOMES and APARTMENTS are classified as either urban or rural, depending upon the communities in which they are located. This makes it possible to reflect the difference in energy types (e.g. district heat, gas) used in urban areas as compared to rural areas. These differences are linked to many factors including regional supply characteristics (e.g. available gas pipelines) and the greater density and size of urban areas. The different energy types used in urban and rural areas, as well as differences in population density also create differing types of pollution problems.

Table 1 shows the disaggregation of the housing stock into home types.

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6 1971 was chosen as a starting year for the calculations in Austria. This was due to the fact that a major building and population census was conducted during that year, thus providing a sound data base. An added advantage of choosing this year is that model results can be compared with the real world, for the first years of a model run.

Table 1 Disaggregation of the Housing Stock into Home Types

Size	Time of Construction	Location of Home
Single Family Homes (SFH)	OLD SFH	OLD urban SFH
		OLD rural SFH
	TOTAL NEW SFH	TOTAL NEW urban SFH
		TOTAL NEW rural SFH
Apartment Homes (APT)	OLD APT	OLD urban APT
		OLD rural APT
	TOTAL NEW APT	TOTAL NEW urban APT
		TOTAL NEW rural APT

Assumptions underlying this disaggregation include:

1) Rural apartments must be less than a specified fraction of all apartments. For Austria this fraction has been assumed to be 10%, since it was found that the fraction of multifamily homes in rural communities (communities with 3000 or fewer inhabitants in the Austrian case) very rarely exceed this amount. [7]

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7 Note: The known variables are urban and rural families (from the population model) and the number of single family and apartment homes (from the housing census). If one assumes that a certain fraction of rural families are housed in apartments (rural families live in communities with 3000 and fewer inhabitants) then all other home types can be determined. NEW HOMES have not been included in Table 1.

3.3 Changes in the Housing Stock

Major determinants of residential energy consumption are the number of occupied housing units and the ratio of single family homes to apartments. Second homes and unoccupied homes have not been included in the calculations.

These determinants are constantly changing. The different components of change considered in this section are construction and demolition, driven by population growth, decline in family size, and replacement of obsolete homes. It is necessary to subtract the losses of homes and to add NEW HOMES to the housing stock in each simulation year. In this simulation of demolition and construction the model keeps track of the number of single family homes and apartments and the age of each home.

In Figure 6 a flow diagram represents the relationship between INCREMENTAL HOMES, REPLACEMENT HOMES, population, family size, demolition and the housing stock. As the flow diagram indicates, the housing stock in year n is first reduced by the number of demolished homes; these are then assumed to be substituted by REPLACEMENT HOMES. In addition population growth and the development of family size create the need for INCREMENTAL HOMES, the other component of NEW HOMES. NEW HOMES as a whole are built according to construction policies, which can be varied over time to reflect changes in lifestyle and technologies in accordance with scenario assumptions. These homes are added to the remainder of the housing stock in year n to form the housing stock in year n + 1.

INCREMENTAL HOMES needed to house new families are responsible for the increase in the number of TOTAL HOMES. REPLACEMENT HOMES needed to substitute for demolished homes do not alter the total number of homes. These two components are discussed in more detail below. (sections 3.3.1 and 3.3.2)

The percentage of NEW HOMES constructed as single family homes and as apartments can be specified for urban and rural areas. These parameters can be changed before or during simulation, thus showing the impact of different settlement strategies and construction policies upon residential energy consumption.

It is important to note that the annual changes of the housing stock are relatively small compared to the size of the total housing stock. Because of the relatively small number of NEW HOMES which are added to the existing housing stock during each simulation year, (depending upon the rate

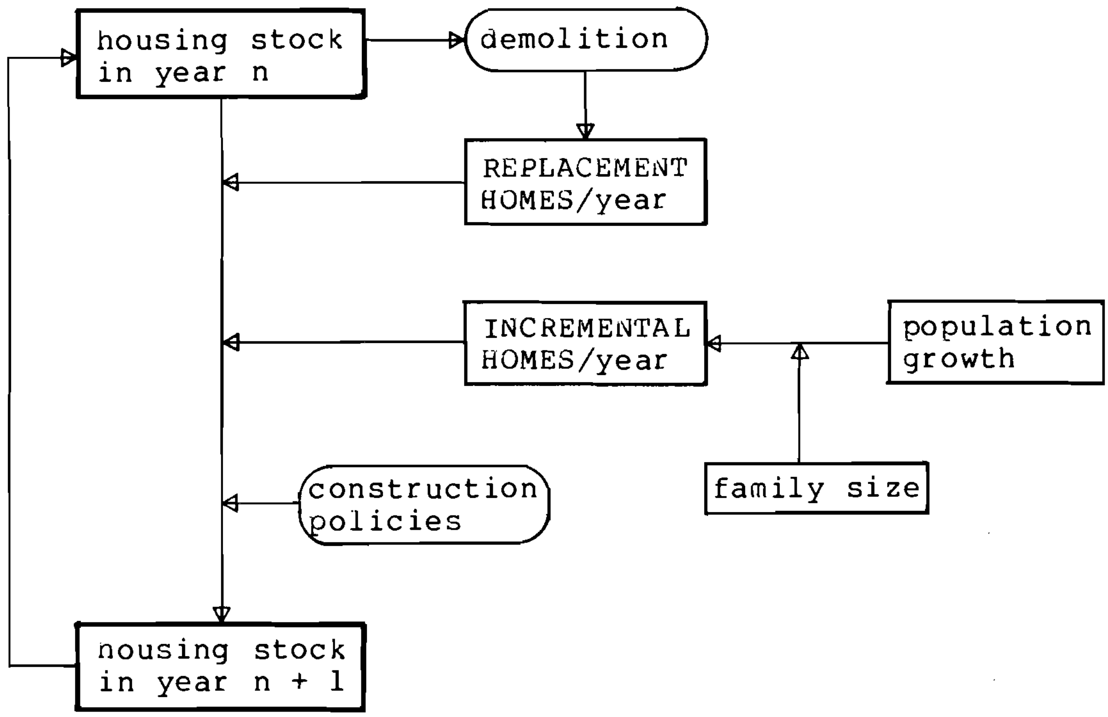

Figure 6 Flow Diagram - Changes in the Housing Stock

of demolition and new families) changes in overall residential energy type mix and insulation levels proceed slowly. More rapid changes require retrofitting of homes, which is considered later in the paper.

After the number of NEW SINGLE FAMILY HOMES/APARTMENTS is determined, home construction policies for a given simulation year are applied. Home construction policies, which are based upon different scenarios, address the major determinants of home energy use such as floorspace, thermal integrity, the kind of appliance and energy type the home is heated with as well as the energy type used for water heating.

Scenario Results and Comments

For Austria, both total population and total number of homes show relative stability over the scenario time frame 1978 - 2015. The total number of homes increases from 2,43 million in 1971 to 3.20 million in 2015. Concurrently, the total population increases from 7.46 million to 8.26 million. By 2015, 46% of the housing stock consists of post-1971 construction. Single family homes account for approximately 44% of the total housing stock in 1971, and for 41% by the year 2015.

Over the time frame of the scenario the number of NEW HOMES increases very slightly from 32.000 in the year 1971 to 36.900 in the year 2000 and 38.600 in the year 2015. The fractions of NEW HOMES compared to the total number of inhabited homes is 1.3% in 1971, and 1.2% by 2015. By comparing model calculations with census data for 1971 to 1977 in the case of Austria it was found that the actual numbers of homes as given by the Austrian census [15] are higher than the model calculations (47.000 versus 32.500 NEW HOMES per anno on the average from the year 1971 to 1976). This can be explained by the fact that the model calculates only the population and demolition driven components of annual construction. Newly constructed second homes are not accounted for in REUMA and these may well be responsible for the higher census figures.[8] An added element of uncertainty lies in poor statistical data about demolished homes and homes which change their function. However, since the model establishes a ratio of one family to one home in the long run, this discrepency seems to be of minor importance.

3.3.1 INCREMENTAL HOMES Needed to House New Families

INCREMENTAL HOMES needed because of demographic trends are defined as homes required to house the net increase in the number of families; this is a function of both population and family size.

The number of families which exceeds the number of homes has been called UNSATISFIED DEMAND and each year a constant fraction of this UNSATISFIED DEMAND is added to the number of INCREMENTAL HOMES. In the long run a ratio of one family to one home is achieved. In Austria the number of families exceeded the number of homes by 107.000 or 4.4% in 1971.

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8 If one adds up the number of annually constructed homes from 1961 to 1971 and compares them to the number of inhabited homes constructed during the same period as given by the main home and building census of 1971 census [16], the number of inhabited homes is 11% lower.

Assumptions

A basic assumption underlying the INCREMENTAL HOME subroutine is that home types are determined by the settlement pattern of families, as simulated by the interface between the population model and REUMA (population allocation model). By means of this interface, increases (decreases) in population are allocated to urban (rural) areas as specified by a given scenario. [9] One new family is assumed to get one home. Should the number of urban or rural families decrease in a region, then the number of urban or rural INCREMENTAL HOMES is set to zero. If this process continues, the number of homes will eventually exceed the number of families. In this case the number of homes is set equal to the number of families. The number of homes exceeding the number of families are considered either to be uninhabited or to have changed to uses other than housing.

It has already been pointed out that the ratio of single family homes to apartments has an important influence upon residential energy consumption. By assigning values to relevant parameters the fraction of rural INCREMENTAL HOMES built as single family homes can be determined and in a similar fashion the urban INCREMENTAL HOMES can be split into single family homes and apartments. These parameters can be changed before or during simulation in order to show the impact of density of settlements upon residential energy consumption.

Scenario Results

Due to the almost stable population in Austria (0.23% increase per anno), INCREMENTAL HOMES which satisfy the housing needs of new families, show a fairly stable pattern over the time frame of the scenario. They account for 13.040 homes built in 1971, 41% of NEW HOMES in that year. By 2000 19.000 INCREMENTAL HOMES are built per year, accounting for 51% of NEW HOMES in that year, and by 2015 20.030 INCREMENTAL HOMES account for 52 % of NEW HOMES in that year. NEW HOMES are the sum of INCREMENTAL HOMES plus REPLACEMENT HOMES for demolished dwellings built in a given simulation year.

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9 e.g. it has to be taken into account that different probabilities of choosing single family homes as compared to apartments exist in urban vs. rural areas. The energy type mix for single familiy homes also differs from the energy type mix for apartments.

The INCREMENTAL HOME subroutine requires detailed information about population and migration on a disaggregated spatial basis. In the OeIR population model [12] a good information base was available for Austria.

Flow Diagram - INCREMENTAL HOMES

Figure 7 below shows a simple flow diagram of the INCREMENTAL HOME subroutine. This subroutine is used for both urban and rural INCREMENTAL HOMES.

3.3.2 REPLACEMENT HOMES Needed to Substitute for Demolished Homes

In this subsection, the demolition-related component of NEW HOMES is discussed. In order to rehouse displaced inhabitants it is necessary to substitute REPLACEMENT HOMES for demolished homes. The number of homes does not change as a result of demolition, though the housing stock will change with regard to ratio of single family homes to apartments[10] and "quality". A new home built to replace an obsolete one will be in many respects different.

"Quality" refers here to a set of parameters which describes the energy demand of a home for space and water heating. These parameters are floorspace, thermal integrity of the home, and the appliance and energy type used for space and water heating. The values for all these variables are determined by the user of the model as he creates his scenarios.

Assumptions

The main cause for demolition is considered to be the substandard conditions i.e. "quality" and/or design of older homes.

In REUMA homes are grouped according to their age in years. A maximum age is determined and homes older than that

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10 One possibility is to simply replace demolished homes with homes of the same type (to replace an apartment with an apartment). An alternative possibility is to replace demolished homes according to a ratio of single family homes to apartments, which is chosen for INCREMENTAL HOMES (see INCREMENTAL HOMES subroutine, section 3.3.1).

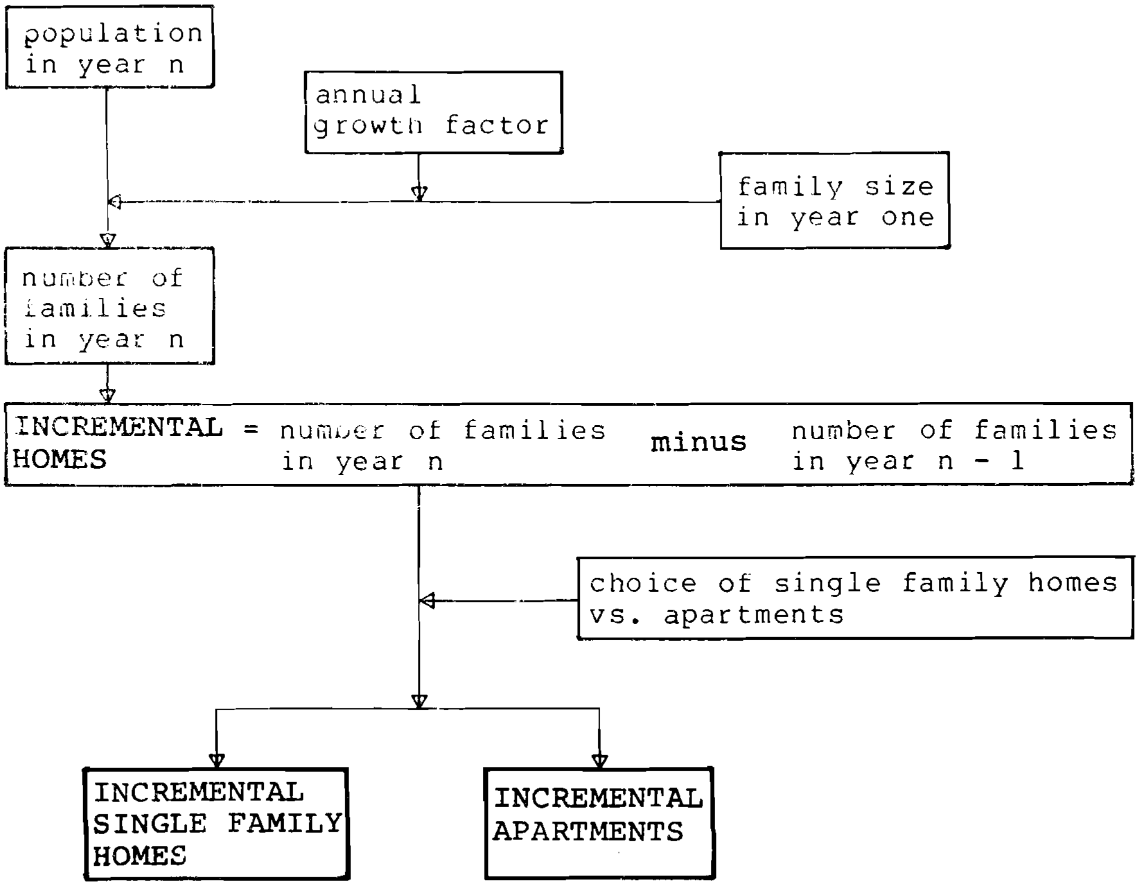

Figure 7 Flow Diagram - INCREMENTAL HOMES Needed to House New Families

maximum age are not assumed to be demolished. They are thought to account for the historically or otherwise valuable fraction of the housing stock which will be maintained throughout the simulation period of the model. The demolition of other homes is straightforward. Each simulation year a certain fraction of the homes in each age group below the maximum age is destroyed or converted to purposes other than housing. The fraction increases exponentially with the age of homes and is assumed not to vary for different home types.

Obviously demolition does not account fully for all losses to the housing stock. Homes also cease to function as residences when they are converted to offices. These changes in function are assumed to occur mostly in centers of cities where services are concentrated and people are moving out. It is thought that these changes in function are age dependent, similar to the probability of demolition of homes.

In Table 2 below the five quality groups used commonly in Austrian building censuses are presented.
Figure 8 shows the age of homes in 1971 and the breakdown into the five quality groups according to age groups. The probability of demolition is also shown in Figure 8. As can be seen from Figure 8 there is in fact a close correlation between age of buildings and the standard of homes. The maximum age up to which homes are demolished was set at 130 years for Austria.

Table 2 Quality Classification of Homes

	Central Heating	Single Oven or "Etagen-Heizung"	Bath / Shower	Toilet within Flat	Water within Flat	Remarks
Group 1	yes	no	yes	yes	yes	
Group 2	no	yes	yes	yes	yes	
Group 3	yes/no	yes	no	yes	yes	}
Group 4	yes/no	yes	no	no	yes	}Substan-
Group 5	yes/no	yes	no	no	no	}dard Homes

Scenario Results

The simulated number of demolished homes in the scenario under study increases slightly from 18,700 in 1971 to 17,870 in 2000 and 18,730 in 2015. The rate of demolition decreases from 0.8% in 1971 to 0.6% in 2000, and declines very slightly until 2015.

Limitations

A limitation of the demolition subroutine is that there is no distinction made between demolition and changes in function of homes. Austrian statistical data and probably most data for other countries are very limited in this area.

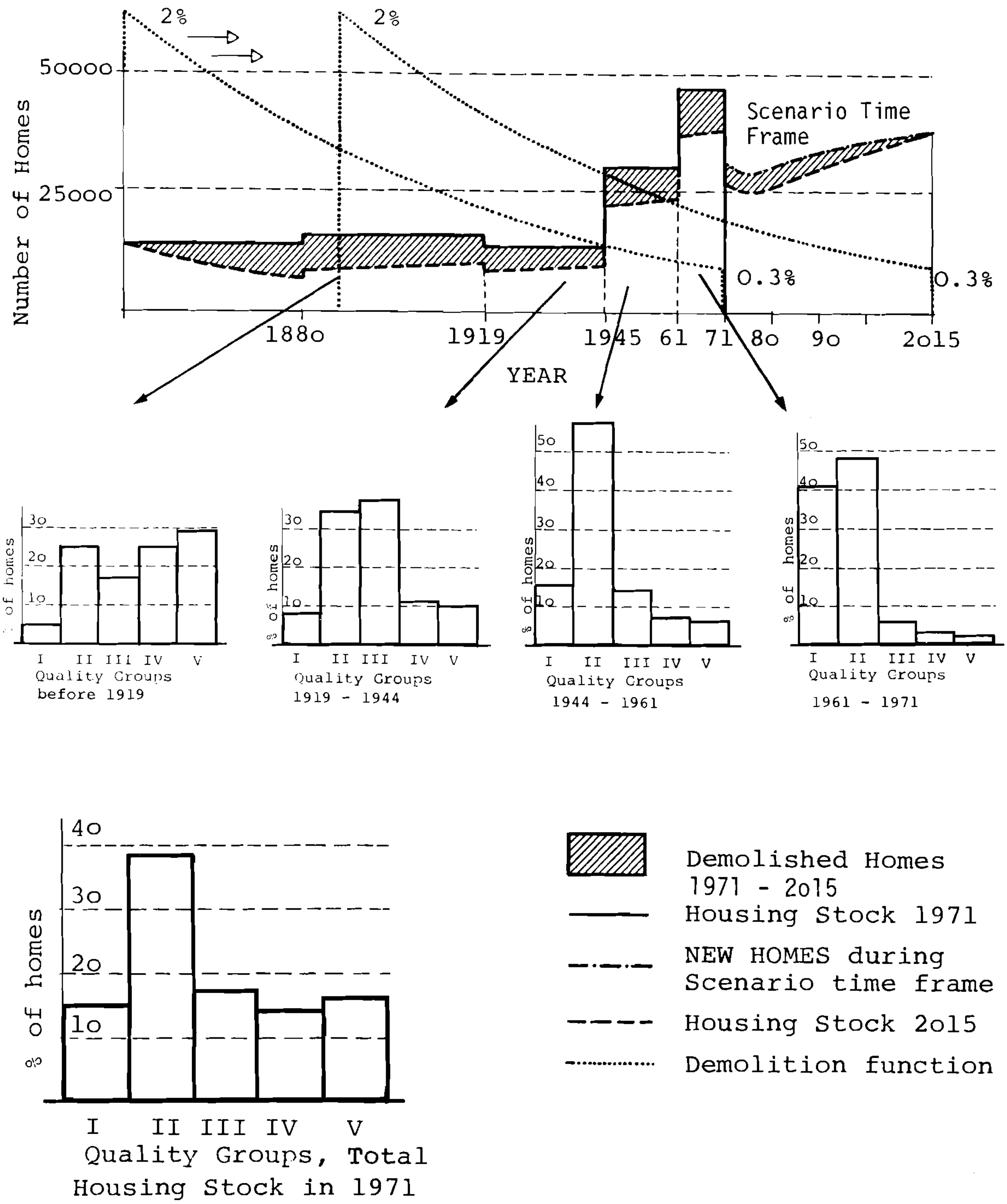

Figure 8 Distribution of Homes According to Quality and Age

Functional Relationships

The functional relationship used in the demolition subroutine is:

$$P_k = [RPK \times e^{(RDM \times k)}] - k_{max}$$

where:

P_k = probability of demolition of a home of a given age k
k = age (1 to k_{max} years)
k_{max} = maximum age

RPK and RDM = estimated parameters

The number of demolished homes within each group of homes k years old is derived from:

$$D_k = H_k \times P_k$$

where:

D_k = demolished homes of homes k years old
H_k = homes k years old

These values can be summed for k = 1 to k = maximum age to calculate the total number of homes demolished in a given year.

Flow Diagram for the Demolition Subroutine

Figure 9 shows a simplified flow diagram for the demolition subroutine.

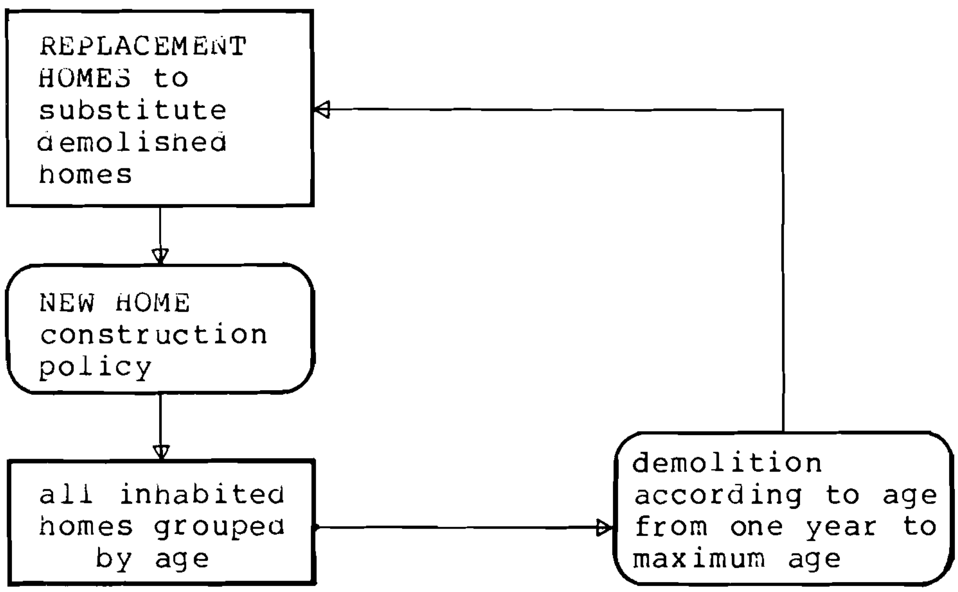

Figure 9 Flow Diagram - Demolition of Homes and Replacement of Demolished Homes

3.4 Energy Types, Heating Appliances and Substitution Processes

In the previous two sections the bookkeeping calculation of the number of occupied homes by home type (i.e. simulation of changes in the size of the housing stock through construction and demolition) was discussed. In this section different energy end uses and energy types are distinguished. For each home type the major determinants of residential energy consumption are the type of space and water heating appliance, as well as the energy types chosen.

In relating home types to the different energy uses and energy types a great variety of combinations can be created. Energy use in a home is broken down into three major groups:

energy use for

- space heating	)	
	)	base appliances
- water heating	)	
- household appliances	)	every appliance which does not fall into the previous category (see section 3.5.4)

Appliances for space and water heating are called base appliances. An important characteristic of base appliances is that they are built into the home and stay with it (except for OLD HOMES where retrofitting can be simulated). It is further important to know the energy type which is used by the base appliance. This will depend on the type of base appliance, the type of home, the time of construction and the price and local availibility of energy types. Six energy types (electricity, gas, oil, coal, wood, district heat plus one alternative energy source like solar and/or heat pumps) have been considered in the Austrian study. This is discussed in sections 3.4.1 and 3.5.3. Furthermore it has been assumed that there is a connection between the choice of heating appliance, the energy type used and heating habits, which is discussed in section 3.5.1.

For Austria it has been assumed that a consumer trend towards a more convenient life style is dominant in the residential sector. Convenient, easily controlled space heating units are adopted, as well as hot water facilities such as showers and baths.

3.4.1 Energy Types and Base Appliances for Space and Water Heating

Two kinds of base appliances are distinguished in the model:

- space heating appliances: these are grouped into either single oven appliances or central heating appliances

- water heating appliances

For all types of homes the base appliance ownership probability is specified. The base appliance ownership probability is the percentage of homes by type having a particular base appliance and using a specified energy type. Six energy types plus one alternative energy source can be considered. The initial values are taken from census data and other related studies. During the simulation run, the ownership probabilities can be changed in order to examine retrofitting of OLD HOMES and changing of construction policies according to assumed shifts towards or away from certain energy types and/or heating systems. REUMA calculates the ownership probabilities for TOTAL NEW HOMES which are the weighted averages of NEW HOMES constructed between the starting year of REUMA and a given simulation year, e.g. the base appliance ownership probability of district heat of apartments built in the starting year of REUMA was assumed to be 20% in the case of Austria; over the time frame of the scenario this probability was assumed to increase to 37% in the year 2015.[11] The weighted average of the base appliance ownership probabilities of district heat of TOTAL NEW APARTMENTS constructed during the 45 year period is 32.8% Ownership probabilities for TOTAL NEW HOMES are not assumed to be changed during the simulation period.

Single ovens [12] and central heating are treated separately, in order to permit one to account for the different technical problems of energy type substitutions for these two base appliance groups, as well as to be able to simulate transitions from one group to the other (e.g. substituting gas, oil, district heat [13] for coal single ovens; substituting district heat and gas for oil quite often includes a shift from single ovens to central heating).

Simulation Technique for Energy Type Shifts

As has been discussed, significant variations in energy type shifts exist for the four home types, OLD SINGLE FAMILY HOMES, OLD APARTMENTS, NEW SINGLE FAMILY HOMES and NEW APARTMENTS. The change in the energy type mix and appliance mix of the housing stock has three components: a) retrofitting of OLD HOMES constructed before the starting year of REUMA, b) NEW HOMES constructed per year c)

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11 As shown in Figure 10 on page 39.

12 Austrian censuses distinguish a further type of space heating appliance, which is called "Etagenheizung". Since "Etagenheizungen" are conceptually closely related to single ovens and account only for approximately 4% of all homes in 1971, Etagenheizungen and single ovens are subsumed under the term single ovens.

13 REUMA does not include considerations about the basis of district heat (e.g. coal based district heat, oil based district heat, etc.).

demolition of homes.

In considering changes in energy type mix one has to take into account that each energy type has a spatial dimension which is determined by the necessary density of consumers. For instance, a district heat or gas network needs a certain density of consumers in order to operate economically. This density most often is found in settlements in which apartments are emphasised. Energy types and thus to a certain extent base appliances for single family homes and apartments are essentially different. Another important distinction has to be made between retrofitting of OLD HOMES (where technical, legal and financial problems arise) and base appliances and energy types for NEW HOMES.

These differences make it necessary to simulate changes in energy type mix and appliances individually for these four major home types. As well, simulation of changes in energy type mix must be performed separately for each type of base appliances (single oven heating, central heating, water heating).

In order to examine energy type shifts over the scenario time-frame, three matrices containing the probabilities that a home of a specified type will have a particular base appliance using a given energy type in a given year have been constructed.

The initial matrix for the starting year (1971) was taken from census data, and used as data input for REUMA. A second matrix with the probabilities for a year in the near future was derived from census data and from trends of the recent past. This was done because of lack of data for the regions. When census data become available, the estimation precedure should be based on time series analysis. A third matrix, for approximately the last third of the scenario time frame, (i.e. for the year 2000) was constructed on the basis of assumptions about energy type shifts and trends towards certain base appliances. These assumptions implicitly include future energy prices, availability of energy types and environmental considerations (see section 3.5.1).

In a submodel exogenous to REUMA these three probability distributions for a given home type were used to determine transition matrices corresponding to a Markov chain with constant transition probabilities whose stable values are approximately equal to the hypothetical values in the year 2000. These transition matrices have been included in the data base and produce in combination with the matrices for the starting year the desired probability distribution for the different home types for each simulation year.

Table 3 shows how the data for energy use and base appliance ownership probabilities are organised in matrix form. Seven energy sources (electricity, gas, oil, coal, wood, district heat, and an alternative energy source) have been considered. The summation of the probabilities for space heating and for water heating for a given home type usually equals one. However, in the case of Austria, the sum of probabilities for water heating of OLD HOMES has been set to less than one. It is assumed that the value of one is gradually approached by 1990, as all homes are gradually fitted with a bath or shower.

Table 3 Data Organisation for Matrices

<table>
<tr><th colspan="3">Home Types</th><th>Energy Types</th><th>1</th><th>2</th><th>oil</th><th>4</th><th>5</th><th>6</th><th></th><th>Alternat. Energy</th></tr>
<tr><td rowspan="6">PRE 1971 H</td><td rowspan="3">SFH</td><td rowspan="2">space heat</td><td>s. o.</td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="2">sum=1</td><td></td></tr>
<tr><td>c. h.</td><td></td><td></td><td>x</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">not water</td><td></td><td></td><td></td><td></td><td></td><td></td><td>sum=1</td><td></td></tr>
<tr><td rowspan="3">APT</td><td rowspan="2">space heat</td><td>s. o.</td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="2">sum=1</td><td></td></tr>
<tr><td>c. h.</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">hot water</td><td></td><td></td><td></td><td></td><td></td><td></td><td>sum=1</td><td></td></tr>
</table>

SFH ... Single Family Home APT ... Apartment homes
H ... Homes
s. o. ... single oven appliances
c. h. ... central heating appliances

Split into Urban and Rural Components

Each of the matrices for a given home type[14] has to be

14 The four home types are: OLD SFH, OLD APARTMENTS, NEW SFH, and NEW APARTMENTS; SFH = single family homes.

split into an urban and rural component, in order to match them with the eight home types.[15] The distinction made in this study between an urban and rural component was of greatest importance for environmental impacts; the distribution of single family homes and apartments on the urban-rural continuum does not alter the overall energy consumption as long as no differences in life style or technical parameters concerning performance of heating appliances are introduced. The energy types and their use are allocated to urban and rural areas in order to allow an evaluation of environmental pollution stemming from residential settlement patterns.

Since data based directly on community size was not available for Austria, indicators of community size had to be used. The microcensus data of 1975 [17] and 1977 [18] was a great aid in the analysis of the variation in the mix of energy types and base appliances in urban vs. rural homes. The microcensus provided data based upon the ratio of the total population of a community to people engaged in agricultural work (agrarian quota) by community size. As one would expect, there is a close correlation between agrarian quota and community size. Communities of 3000 and less population, which are defined in the population allocation model as rural, have an agrarian quota consistantly higher than 10%. Conversely, communities with 3000 and more inhabitants have an agrarian quota consistantly lower than 10%.

Table 4 shows how the microcensus data is organised [17,18]. For each of these community types the ownership fractions for base appliances and energy types can be derived from the microcensus data. The great differences in distribution of energy types for heating within the seven community types are displayed in Figure 10 below. At the present stage of development of REUMA the matrices for the four home types (OLD SINGLE FAMILY HOMES, NEW SINGLE FAMILY HOMES, OLD APARTMENTS, NEW APARTMENTS) are split each year into two identical matrices for the urban and rural component of the home type.

As a next step in the development of the model it is suggested that the array for space heating of one home type (i.e. NEW SINGLE FAMILY HOMES which contains 12 components[16]

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15 The eight home types are: OLD urban/rural SFH, urban/rural APARTMENTS, NEW urban/rural SFH, urban/rural APARTMENTS; The matrices for TOTAL NEW urban/rural SFH and TOTAL NEW urban/rural APARTMENTS are the weighted average of the respective NEW HOME types. SFH = single family homes.

Table 4 Community Types Based upon the Agrarian Quota

	Community Size	Agrarian Quota
1)	communities with less than 20.000 inhabitants	more than 30%
2)	- " -	20.1% - 30 %
3)	- " -	10.1% - 20 %
4)	- " -	5.1% - 10 %
5)	- " -	up to 5 %
6)	communities with 20 000 to 250 000 inhabitants	
7)	Vienna	

Source: [12,13]

adding up to 100%) be split into two arrays.

Historical Trends of Energy Type Substitution and Retrofitting in Austria

The energy type mix for space heating has shown strong shifts in the recent past, according to Austrian census data [19,20,21,22]. In the year 1969 about 83% of Austrian homes were heated with coal or wood (coal 61%, wood 22%) mostly in combination with single ovens. Oil was used by 10% of all homes. By the year 1977 the fraction of homes using solid energy types dropped to 46% (coal:29%, wood:17%). Concurrently the use of oil has climbed to 26% of all homes.

On the basis of these trends it is assumed that the use of coal will be nearly phased out by the year 2000; wood, however, will maintain its importance in rural areas, due to its availability and low costs. Convenient energy types like oil, gas, electricity and district heat are likely to continually gain in importance in the residential sector as a whole. Figure 12 on page 44 shows the percent of homes

16 The twelve components are: the ownership probabilities that a home of a given type is fitted with single ovens and uses one out of six possible energy types, or is fitted with central heating and uses one out of six possible energy types; compare with Table 3, Data Organisation for Matrices.

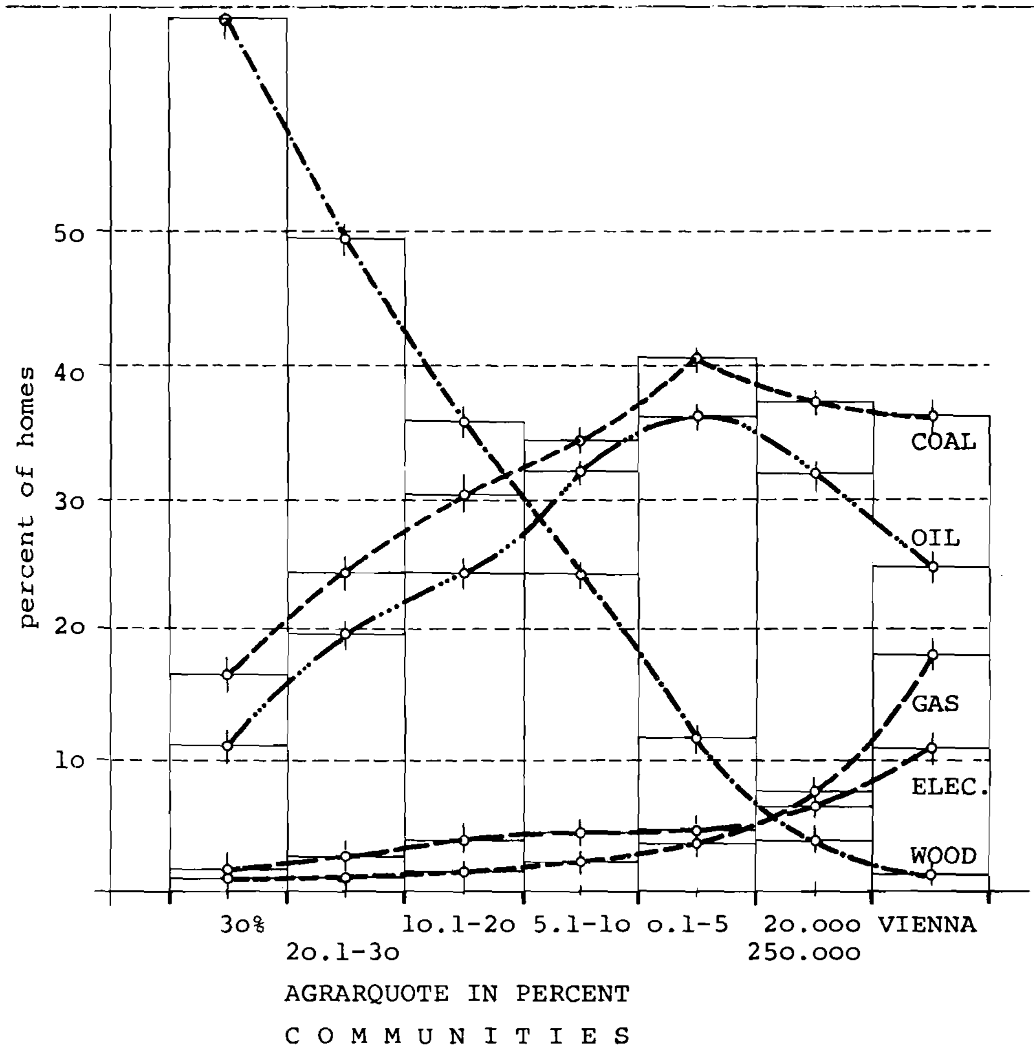

Figure 10 Distribution of Energy Types for Space Heating by Community Type

using each energy type for space heating in the scenario. The historical values for 1969 to 1978 as given by the Microcensuses [19,20,21,22,23] are included in Figure 12.

Interlinked with the shift towards convenient energy types during the scenario time frame is the trend towards convenient space heating appliances. In 1969 90% of all homes were heated with single ovens and 10% were centrally heated. In 1977 70% of all homes were heated with single oven and already 25% were centrally heated.[22] [17] In the

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17 Etagenheizungen and single ovens are subsumed under the

scenario 46% of all homes are assumed to be fitted with central heating by 2000, and 62% by 2015. These trends towards central heating systems differ for single family homes and apartments, NEW HOMES and retrofitted OLD HOMES.

Just as a trend toward convenient energy types and space heating appliances was assumed to occur in the scenario, it is foreseen that homes will be rapidly fitted with baths or showers. According to census data of 1961 only 29% of Austrian homes had a bath or a shower [24]; by 1971 this fraction increased to 53% [16] and by 1977 to 72% [25]. The actual number of homes fitted with a bath or a shower approximately doubled between 1961 and 1971 and tripled between 1961 and 1977. In the scenario it is assumed that by 1990 nearly all homes are fitted with a bath or shower. This is achieved by retrofitting pre-71 (OLD) HOMES and fitting 100 per cent of NEW HOMES with baths or showers. Convenient energy types such as electricity, gas, and oil are assumed to be used for these hot water appliances.

Energy Type Substitution (Retrofitting) of OLD HOMES

There is a high correlation between substandard housing conditions and the age of homes. This problem of substandard housing can be attacked by demolition and reconstruction of homes with substandard conditions. [18] Retrofitting has also become an important option in the recent past and is included in REUMA. However, the retrofitting routine can be bypassed by the user if he wishes.

In Austria the quality of the pre-1971 housing stock (OLD HOMES) is still dominated by many homes with substandard conditions. Table 5 shows the distribution of homes for the years 1961, 1971, and 1976 into the quality groups defined in Table 2, which present the totals and percentages in each group.

Group 1 contains the homes fitted with central heating, toilet, and a bath or a shower. In contrast housing units in Group 5 have neither toilet nor water inside. The significance of Table 5 lies in the rapid trend that it shows toward higher quality houses of Group 1 or 2. Though

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term single ovens. The missing 5 percent account for unknown appliances.

18 The term substandard conditions refers here to the type of energy type and type of base appliance used.

Table 5 Distribution of Homes According to the Five Quality Groups for the Years 1961, 1971, 1976

Quality groups	Number of Homes 1961	1971	1976	Percentage of Totals 1961	1971	1976
Group 1	90,000	358,626	832,000	4.2	14.75	32
Group 2	480,000	928,780	954,000	22.3	38.19	37
Group 3 }		409,195	286,000		16.83	11
Group 4 }	1,582,775	350,138	310,000	73.5	14.40	12
Group 5 }		385,163	188,000		15.84	7
Total	2,152,775	2,413,902	2,546,000	100%	100%	100%

See Table 2 for Definition of Quality

some substandard homes (Groups 3,4, and 5) will be demolished, many will be retrofitted. For example in Table 5, at least 50% of the difference in the number of homes in Group 1 in 1976 compared to 1971 can be accounted for by retrofitting.[19] In this context retrofitting means changing base appliances and/or energy types in order to provide more convenience.

Retrofitting of pre-1971 (OLD) APARTMENTS is difficult and costly (in 1971 91% had single ovens, two thirds of these using solid fuels [20]). Ownership patterns do not usually permit the united effort needed for retrofitting all homes in an apartment block with central heating or district heat. Thus energy type shifts occur for the most part without a change in the type of heating appliance, e.g. a coal single oven is most often replaced by an oil or gas single oven.

Homeowners of pre-1971 (OLD) SINGLE FAMILY HOMES usually show more initiative. Thus a more rapid shift towards convenient appliances is assumed for this component of the housing stock. The change in heating habits which accompany energy type shifts is discussed in more detail in section 3.5.1.

19 This is based upon the assumption that the total construction from 1971 to 1976 (235.000 homes) was in group 1. No allowance is yet made for second homes included in this construction figure.

Energy Types Chosen for NEW HOMES

The base appliance ownership probabilities for NEW (= annually constructed) HOMES can be changed for every simulation year. The base appliance ownership probabilities for TOTAL NEW HOMES (TOTAL NEW HOMES are the sum of NEW HOMES constructed between the starting year and a given simulation year) are the weighted averages of ownership probabilities for NEW HOMES constructed each year. No energy type substitution is assumed for TOTAL NEW HOMES during the scenario time frame.

In Austria NEW SINGLE FAMILY HOMES are fitted to a high percentage with convenient energy types and base appliances, and belong to Group 1 or 2 in Table 2. However, the use of wood is expected to continue, mostly in rural areas and always in connection with central heating.

It is assumed that NEW APARTMENT HOMES are also fitted with convenient energy types and base appliances. Here emphasis is on energy types like district heat and gas.

Scenario Results

Figure 11 shows the examples of assumed changes in energy type mix and base appliances over time in relation to the home type ((pre-71) OLD SINGLE FAMILY HOMES, pre-1971 (OLD) APARTMENTS, NEW SINGLE FAMILY HOMES, and NEW APARTMENTS). The probability that a home of a given type will have central heating is shown by the top curve in Figure 11 a. The six additional curves in Figure 11 a show the probability that these homes use electricity, gas, oil, coal, wood or district heat for their central heating systems. The probability that a home of a given type will be fitted with a single oven is similarly shown by the top curve in Figure 11 b. The six additional curves in Figure 11 b show the probability that these homes use electricity, gas, oil, coal or wood for their single ovens.

Figure 12 shows the percent of all homes using each energy type for space heating in the scenario. The historical values for 1969 to 1978 as given by Microcensuses [19,20,21,22,23] are included in the Figure. The model calculates overall percentages as a result of the assumed trends for the individual home types as discussed in this section.

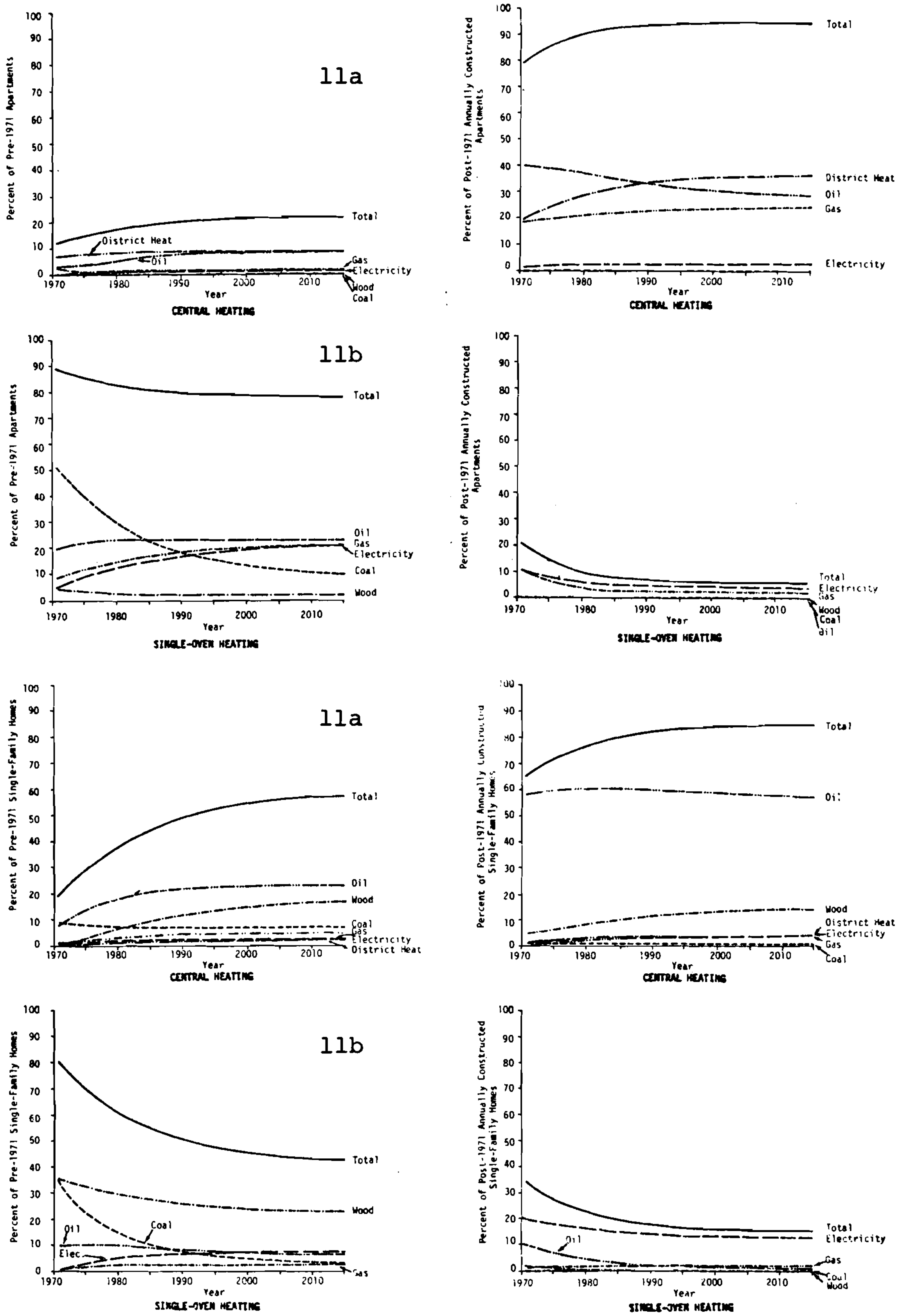

Figure 11 Changes of Energy Type Mix and Base Appliance Mix by Home Type

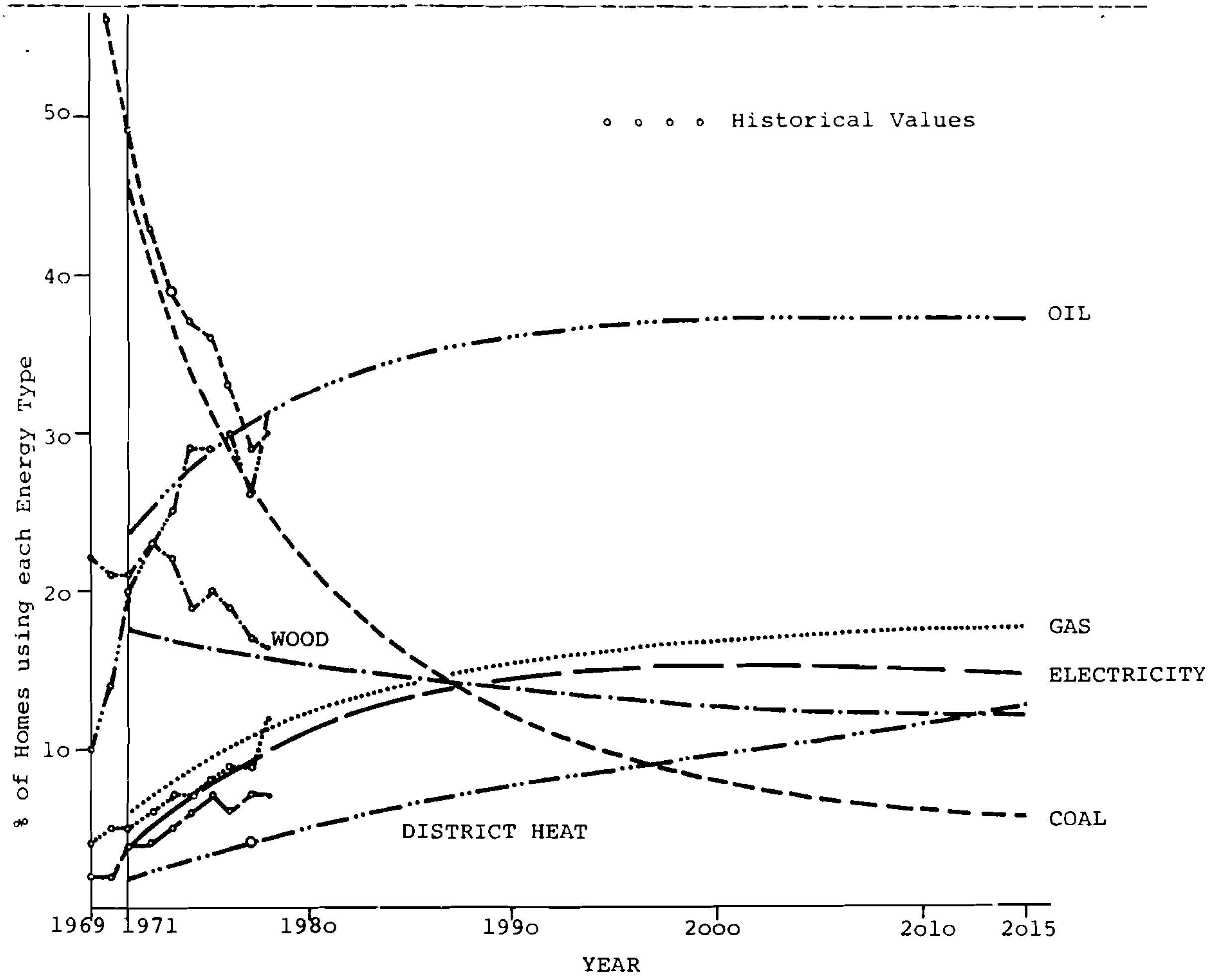

Figure 12 Energy Type Mix for Space Heating - Historical Trends and Model Simulations 1978 - 2015

3.5 Energy Demand, Life Style and Applied Technologies

In the previous sections it has been described how the number of homes of a given type and the kind of base appliance and energy type is determined on an annual basis. In this section the method of calculating the energy use by energy type is outlined.

The amount of energy type F used for space heating during the winter is determined by the formula:

$$C_{T,B,F} = \frac{L_T \times S \times H_T}{E_{T,B,F} \times f_{T,B,F}}$$

where:

$C_{T,B,F}$ = annual amount of energy type F for space heating
L_T = Heat loss per square meter per hour per home type
S = average size of a single family or apartment home
H = Heating hours per year
E = average annual heating system efficiency
f = Factor to indicate demand characteristics associated with certain energy types or heating systems; for instance, homes using coal or wood fired single ovens heat only half of their floorspace at any one time

subscripts:

T home type
B base appliance type
F energy type

From the above equation, it can be seen that there are two complementary ways to explain and to reduce energy requirements for heating:

- The behavioral or life style approach, including measures which encourage residents to heat fewer hours per year and to lower the average room temperature.

- Applied technological measures which do not affect comfort like a) decrease of heat loss figures through improved thermal integrity of homes and b) an improvement in average annual heating system efficiencies.

3.5.1 Life Style and Energy Use

REUMA gives the user the capability of examining the influence of life style changes upon energy use at various levels of disaggregation.

The most general possibility is to set a parameter to values above or below one, which will affect the overall level of energy use in a general, non specific way. Thus, for instance, a change in the number of heating degree days can be examined.

Average Annual Heating Hours

Public attitudes towards energy use in connection with space heating can be reflected in the assumed average annual heating hours per home. This can be done independently for urban single family homes, urban apartments and rural single family homes and rural apartments. It has been assumed that these figures do not depend upon on whether the home is OLD or NEW; however it is possible to examine variations in urban versus rural homes and single family homes versus apartments.

Average annual energy use for water heating can be determined for these home types and additionally for OLD, NEW, and TOTAL NEW HOMES. However, it is doubtful if there is sufficient information available to permit use of this feature of REUMA.

Lifestyle and Construction Policies - Floorspace

In section 3.3 the calculation of the number of NEW HOMES each year was explained. Here the question examined is how lifestyle is reflected in construction. It has been assumed that a relevant variable which reflects lifestyle in this connection is the size of NEW HOMES. By determining the floor area of NEW SINGLE FAMILY HOMES and APARTMENTS, trends towards more or less floorspace per capita can be simulated. The home size of OLD SINGLE FAMILY HOMES and OLD APARTMENTS is derived from census data. REUMA can be used to calculate average floor space per capita for all homes, for all single familiy homes, for all apartments, for OLD, TOTAL NEW, and NEW HOMES, etc.

Figure 13 shows present trends in the growth of floorspace in Austria. The average size of a pre-1971 (OLD) HOME is 66.5 m^2 (apartments = 53 m^2, single family home = 83 m^2) [16]. The average size of homes constructed in the year

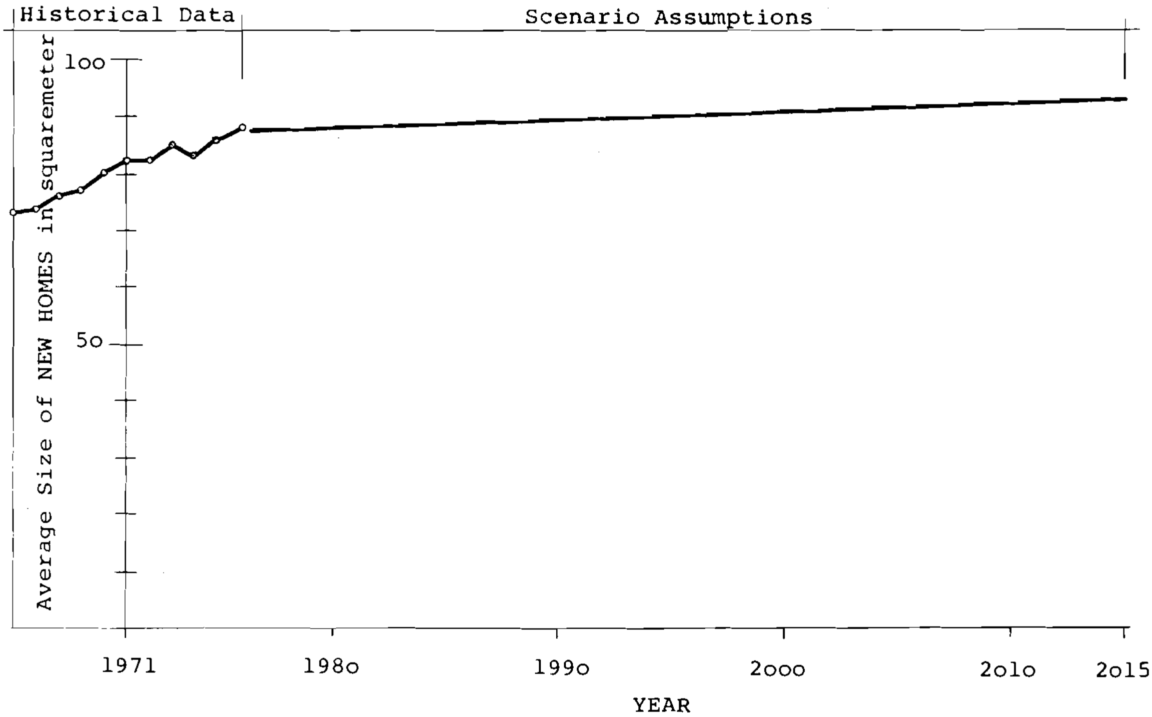

Figure 13 Growth in Floorspace of NEW HOMES 1966 -1976

1971 was 82 m^2 (on the average apartments were 67 m^2 and single family homes were 105 m^2) [26]. The average floorspace per capita for Austria in 1971 was 22.6 m^2.

If one assumes that the floorspace per capita increases at a moderate rate of 0.4 m^2/year (starting from 1971 values), then an average floorspace per capita resulting from these assumed construction trends and to a certain extent from the assumed decline in family size is 29 m^2/capita in the year 2000 and 32 m^2/capita in the year 2015.

Heated Floorspace

Additionally one has to take into account that the choice of the energy type for heating and type of heating system, an indication of life style, as discussed in section 3.5.1, also influences space heating habits. The amount of heated floorspace of a housing unit of a given type, which is related to the convenience of the energy type, the heating appliance, and expected relative energy retail prices can be specified by the user of REUMA.

Similar to the data organisation underlying ownership probabilities for energy types and base appliances, as shown in Table 4, matrices for the eight home types[20] have been created with information about space and water heating habits. A value of 1 in this matrix means that the entire floorspace of a home of a given type is heated, or that the full average amount of hot water per household assumed in the scenarios is used. Values above or below 1 indicate more or less energy use for a given energy type, a given base appliance and a given home type. Thus by simulating shifts in energy types and substitutions of base appliances, a positive or negative effect upon energy demand can be examined.[21]

An important assumption for Austria in this context is that homes with coal- or wood-fired single ovens (approximately two thirds of all homes in the year 1971 [20]) heat only half of their floorspace at any one time;[22] on the other hand homes using convenient energy types and/or space heating appliances are assumed to have their entire floorspace heated.

Homes constructed after 1971 are in general not fitted with single ovens using solid fuels. As well, convenient energy types are increasingly substituted for solid fuels in pre-1971 (OLD) HOMES. The use of convenient energy types such as electricity, gas, oil, and district heat has the effect that most often the entire floor space of a dwelling unit is heated, rather than just single rooms. For this reason, the amount of heated floor space per capita increases even more steeply than a look at the construction of bigger NEW HOMES and declining family size suggests.

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20 The eight home types are: OLD urban/rural SFH, urban/rural APARTMENTS, NEW urban/rural SFH, urban/rural APARTMENTS; SFH = single family homes. The values for TOTAL NEW HOMES are the weighted averages of NEW HOMES constructed between the starting year and a given simulation year.

21 In order to keep the number of matrices used to a minimum, the matrix for space and water heating habits has been multiplied with the matrix of efficiencies of base appliances, which is organised in the same way.

22 In the model this was achieved by multiplying the efficiencies of coal or wood fired single ovens with 0.5 for all home types.

3.5.2 Energy Demand, Heat Loss and Efficiencies

Heat Losses

As long as energy prices were low and energy supplies were abundant, little attention was paid to insulation measures. In the wake of growing awareness of the environmental damage of residential energy use in urban areas and the rising cost of energy, the reduction of heat losses through insulation has become a major issue.

REUMA permits examination of the consequences of policies for lowering the heat losses in all home types. [23] The variables reflecting the heat losses of TOTAL NEW HOMES homes as a whole are the weighted averages of the heat losses of NEW HOMES built each year. e.g. the heat loss of apartments built in the starting year of the model was assumed to be 90 kcal/square meter/hour in the case of Austria; over the time frame of the scenario the heat loss of NEW APARTMENTS was assumed to decrease on a stepwise basis to 36 kcal/square meter/hour in the year 2015 as shown in Figure 16 on page 59. The weighted average of the heat losses of NEW APARTMENTS constructed during the 45 year period is 55 kcal/square meter/h. [24] It is important to note that the reduction of average heat losses for the OLD and TOTAL NEW housing stock can only preceed very slowly, due to the great number of homes involved and constraints of capital, material and labour force. Heat losses for NEW HOMES can be lowered significantly in a relatively short time by appropriate regulations and training programs for the participants in the construction field; however this number of homes is small compared to the overall housing stock.

There is in general agreement that the heat loss of an average Austrian home can be reduced by 50 to 60 % of the present level if an efficient insulation policy is applied [27]. The average heat loss figures for the six home types in the starting year 1971 and the possible components of

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23 OLD SINGLE FAMILY HOMES/APARTMENTS, TOTAL NEW SINGLE FAMILY HOMES/APARTMENTS, and for NEW SINGLE FAMILY HOMES/APARTMENTS. Urban vs. rural variations are not assumed.

24 For the calculation of the average heat losses no further reduction of heat losses of post-1971 (TOTAL NEW) APARTMENTS was assumed.

change have been listed below in Table 6. Urban vs. rural variations in heat losses are not assumed.

Table 6 Heat Losses

Home Type	Time of Construction	Average Annual Heat Loss kcal/sqm/h	Components of Change
	OLD SFH (pre-71)	120	demolition; retrofitting of remainder
Single Family Homes (SFH)	NEW SFH =constructed in 1971	120	improvement for NEW SFH
	TOTAL NEW SFH =constructed post-71		demolition retrofitting of remainder
	OLD APT (pre-71)	90	demolition; retrofitting of remainder
Apart ments (APT)	NEW APT constructed in 1971	90	improvement for NEW APT
	TOTAL NEW APT constructed post-1971		demolition; retrofitting of remainder

The average annual heat losses for OLD HOMES (pre-71) and for NEW HOMES in 1971 are assumed to be the same in Austria, however the respective heat losses have different causes.

The assumed average heat loss figures for pre-71 (OLD) and post-1971 (TOTAL NEW) HOMES as well as for annually constructed (NEW) HOMES can be changed by the user of REUMA for a given simulation year. Each year the number of NEW HOMES is added to the number of TOTAL NEW HOMES and new average heat losses of TOTAL NEW HOMES are calculated. It should be noted that figures on average heat losses and average heating hours are "soft" data.

Base Appliance Efficiencies

The model calculations for energy demand are based on matrices (similar to those in Table 3) containing information about heating system efficiencies for the combinations of three base appliances, the seven possible energy types used and the twelve home types. These efficiencies can be changed independently for 252 different combinations for each simulation year.[25]

3.5.3 Alternative Energy Sources for Space and Water Heat

In REUMA there is an option to evaluate the penetration of unconventional energy sources in the residential sector. It has been assumed that future innovative energy technologies for the residential sector will be limited to small scale technologies applicable to single family homes, like solar energy and heat pumps. The technologies are assumed to require a supplementary system using conventional energy sources. The fuel savings achieved by alternative energy technologies is expressed in terms of the amount of energy which would have been otherwise used by the backup system. This process can be considered as a substitution of a new space or water heating technology for a conventional space or water heating technology.

Substitution Model

The extent to which technological substitution will occur has been the subject of many research efforts. R. H. PRY [28] and T. C. FISHER [29] recently developed a simple model for forecasting the substitution of new technologies and this has been used as a basis for studying such substitution in REUMA.

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25 Especially in this area the available data is "soft" and limited.

The Basis of the Substitution Model

In REUMA patterns of substitution are based on following assumptions (similar to those of Pry and Fisher):

- Many technological advances can be considered as potential substitutes for existing technologies.
- It has been shown by Pry and Fisher that in the past the data showing the substitution of one technological process for another follows an S-shaped curve remarkably well.
- If a substitute technology has captured a small share of the market it will eventually dominate it as it improves technologically and becomes cheaper.
- The rate of substitution of new for old technologies is proportional to the remaining amount of the old technologies.

The total substitution process can be characterized by two parameters (delta t and t_o).

Functional Relationships

$$\text{alpha} = \frac{2 \ln 9}{\text{delta } t}$$

$$f(t) = \frac{\exp \text{alpha} \, (t - t_o)}{1 + \exp \text{alpha} \, (t - t_o)}$$

where:

f(t) = fraction of the total potential that has been taken over by time (t)

delta t = "take over time" the time period required to increase the market share from 10 to 90 %

t_o = time when substitutions are half complete

alpha = constant rate that can be defined in terms of delta t

Since every home cannot be fitted with an alternative energy type technology, certain assumptions about limitations in substitution have been made:

- Alternative energy technologies are only feasible for a certain fraction of single family homes. (Direction of roof and the microclimate must be appropriate.)
- The fractions of the total energy demand which can be provided for room heating (app. 50%) and water heating (app. 70%) has to be determined by the user of the model.
- The remaining fraction of energy will be provided by conventional heating systems (the back up system). This auxiliary heating system must be appropriate for automatic control.
- Electric and gas single oven heating systems are assumed to be uneconomical in combination with alternative energy technologies because of the additional construction required.

All assumptions can be changed before or during simulation. The possible impact of alternative energy sources on energy requirements is discussed in detail in section 4.2.

3.5.4 Household (secondary) Appliances

In the previous sections energy use and energy types for space and water heating have been considered. In this section secondary or household appliances (all energy-consuming appliances except appliances used for space heating and/or water heating) are discussed. Fourteen single secondary appliances or groups of small appliances have been considered. All secondary appliances are assumed to use electricity except for gas stoves and gas driers.

Assumptions

It was assumed that secondary appliances tend to move with a homeowner and in the long run will not depend significantly on whether he is living in an urban or rural apartment or in an urban or rural single family home. Though ownership patterns of some kinds of secondary appliances (e.g. freezers in the case of Austria) vary significantly by home type, secondary appliance ownership fractions have been treated as regional averages without regard to home type.

Saturation curves define ownership fractions per home for a set of 14 appliances (washing machines, cooking stoves, televisions, etc.). The 14 appliances selected for Austria are listed in Table 7. The ownership fraction is the percentage of all homes which contain a secondary appliance of a given kind. The ownership fractions of secondary appliances can be changed over time. This is simulated by growth curves determined by the starting and saturation values and the time until the half-saturation point is reached. The level and rate of saturation for each appliance is related to the growth of GNP and personal disposable income. Additional variables taken into consideration are the price of electricity and gas, and the price of appliances. No quantitative statistical relationship between these variables and the level and rate of saturation for each appliance has been established. The relevant elasticities are probably not known well enough in Austria in order to permit the formulation of an econometric approach. We have used judgement rather than an explicit economic method to relate growth of GNP to the use and consumption patterns of secondary appliances. By changing the saturation values and the time until the half-saturation point is reached, different economic scenarios can be studied.

The parameter for the average annual energy consumption of a given kind of secondary appliance can be changed during a simulation run of REUMA.

Scenario Data

Figure 14 shows as an example the saturation curves of 14 household appliances used for Austria in the conservation scenario. The energy consumption per appliance per home has been held constant over the simulation period, but the decreasing household size implies increased appliance use per capita. In 1971 the appliance use per capita per annum was 495 x 10^6 cal. As a result of the increased ownership of appliances this is assumed to increase to 990 x 10^6 cal per capita per annum in the conservation scenario by 2015. It should be noted that the data available for appliance use is "soft". Microcensus data has been used as a basis for the starting values of appliance ownership [33].

Table 7 Summary and Average Annual Energy Consumpion of Household Appliances

Secondary Appliance Electricity		Ave. annual energy use in kwh/anno as given by various. Austrian Sources [30]	[31]	[32]	Values chosen for 1971 1)	Appliance Ownership % 2)
1	refrigerator	300	440	350	250	84
2	freezer	600	880	700	500	22
3	dishwasher	600	1310	1000	750	3
4	clothwasher	500	730	900	400	50
5	electric stove	1100	1460	580	500	50
6	electric dryer	-	-	900	700	5
7	B&W TV	200	70	35	40	65
8	color TV	-	140	140	140	6
9	small appliances	-	-	-	300	75
10	lights	-	290	700	150	99
11	new appliances I 5)	-	-	-	200	-
12	new appliances II 5)	-	-	-	200	-
		3)	3)	4)		
gas					10^9 cal	
13	gas stove				1100	34
14	gas dryer				700	3

The references for [30], [31], and [32] are given in section 7

1) Values used in this report, average household size: 2.94 persons in 1971.
2) Ownership fractions used for the starting year 1971 of this report.
3) No specification of household size is provided.
4) Values refer to a 4 person household.
5) New Appliances I and II refer to appliances which have not yet achieved a large market penetration, such as saunas, solarien, or new appliances which are not yet on the market.

Flow Diagram for Secondary Appliances

Below in Figure 15 a simple flow diagram shows the calculation of secondary appliance energy use.

Functional Relationships

The total energy consumption in a region for a given type of secondary appliance is:

$$C_n = f_n \times H \times E_n$$

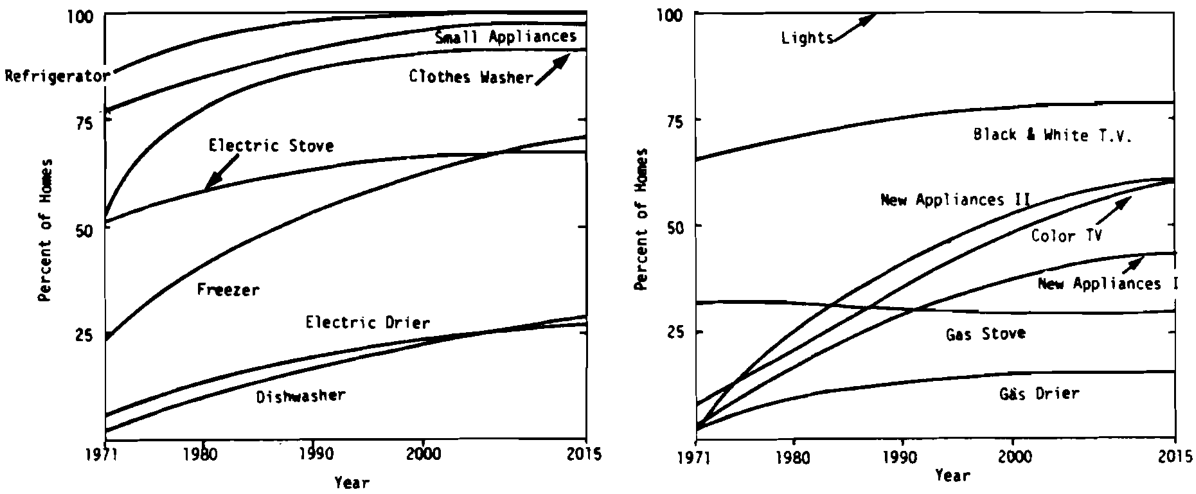

Figure 14 Examples of Saturation Curves for Household (Secondary) Appliances

where:

C_n = yearly energy consumption of secondary appliance type n
f_n = fraction of homes having secondary appliance of type n
H = number of homes
E_n = yearly average energy consumption of one secondary appliance of type n

$$f_{t+1} = f_t + (f_{sat} - f_t) \times (1 - e^{k/t_h})$$

where:

f = fraction of homes having secondary appliance n

subscripts:

(t + 1) in the year t + 1
t in the year t
1 in the starting year
f_{sat} = saturation fraction

k = -0.693
t_h = time until the half saturation point $(f_{sat} - f_1)/2$ is reached

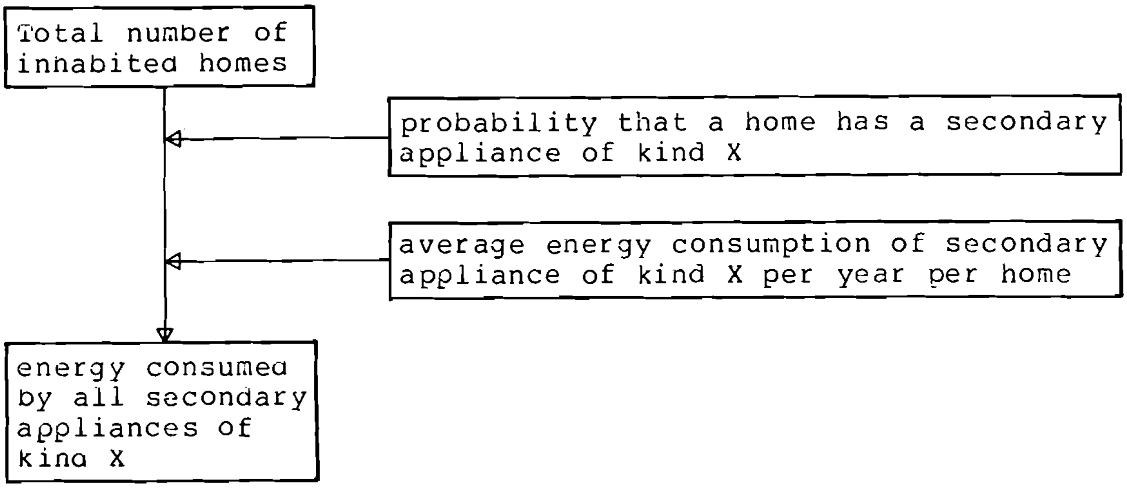

Figure 15 Flow Diagram - Secondary (Household Appliances)

Limitations

The limitation on the use of this component of the model is mainly inadequate data on appliance use.

4 Special Issues and Sensitivity Studies in the Residential Sector

The high degree of parameterization in the model allows one to examine possible impacts of certain types of policy measures through the use of sensitivity studies. The technique used was to make two calculations with the model; in one run only the parameters describing the investigated policy are changed. If the results of these two model runs are compared, conclusions about potential impacts from a policy measure can be drawn. The issues examined in the two following sensitivity studies developed for Austria are the importance of insulation and alternative energy use. The conservation scenario has been used as a reference scenario.

4.1 The Importance of Insulation

The great importance of insulation measures can be studied if all assumptions about reduction of heat losses are removed from the conservation scenario and the results are then compared with a regular conservation case run.

Figure 16 shows scenario assumptions used in the conservation case in regard to the size of NEW HOMES and insulation (shown as heat loss).

- 1 = average annual heat loss (kcal/square meter/h) for OLD (pre-1971) SINGLE FAMILY HOMES.
- 2 = average annual heat loss (kcal/square meter/h) for OLD (pre-1971) APARTMENTS. The average annual heat loss for the two groups of homes decreases over time due to demolition of the most poorly fitted homes and the assumed improvement of insulation in the remainder.
- 3 = average annual heat loss for NEW (annually constructed) SINGLE FAMILY HOMES.
- 4 = average annual heat loss for NEW (annually constructed) APARTMENTS.
- 5 = shows how the average size of NEW SINGLE FAMILY HOMES increases over time.
- 6 = similar for the average size of NEW APARTMENTS

In the sensitivity run no improvements in insulation have been assumed; all other parameters have been left unaltered.

Figure 17 shows a comparison of outputs from these two runs.[26] The shaded areas indicate the potential fuel savings resulting from the simulated insulation measures. It is important to note the time lag involved before the effect of the insulation measures becomes noticeable in the total residential energy demand. An immediate investment has to be made to achieve reduction in heat losses of homes, although this will pay off only in accumulated energy type

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26 The energy use of household (secondary) appliances is included.

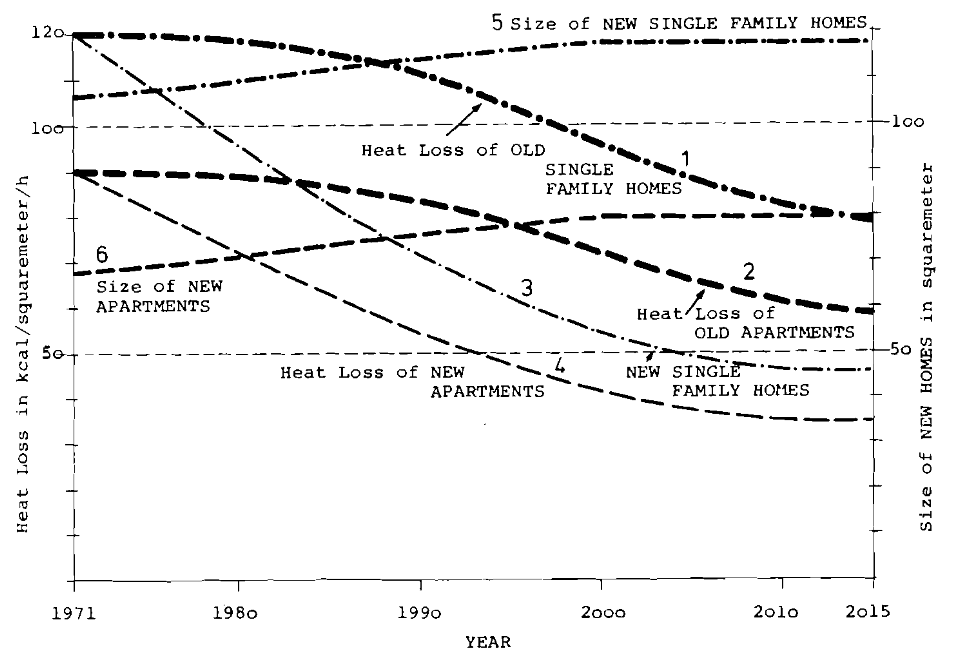

Figure 16 Selected Scenario Assumptions for the Conservation Case

savings over decades. Nevertheless insulation provides one robust approach to energy conservation at the present time, leaving all options open for the future. Added advantages of insulation policies are that they decrease peak demands, reduce the national energy bill, decrease pollution, and are labour intensive (especially in the case of retrofitting of existing homes) and thus have a favourable impact upon the job market. According to a recent study the payback time for the energy invested in insulation material for single family homes is only about 2 months [34]. [27]

Even in the most unlikely case of declining energy prices, environmental considerations would be still an important argument in favour of a conservation policy, especially in urban areas.

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27 the payback time for the energy invested in heat pumps according to this study is 5 to 14 months, for solar energy 16 to 23 months. Conventional oil central heating has been used as a comparative system.

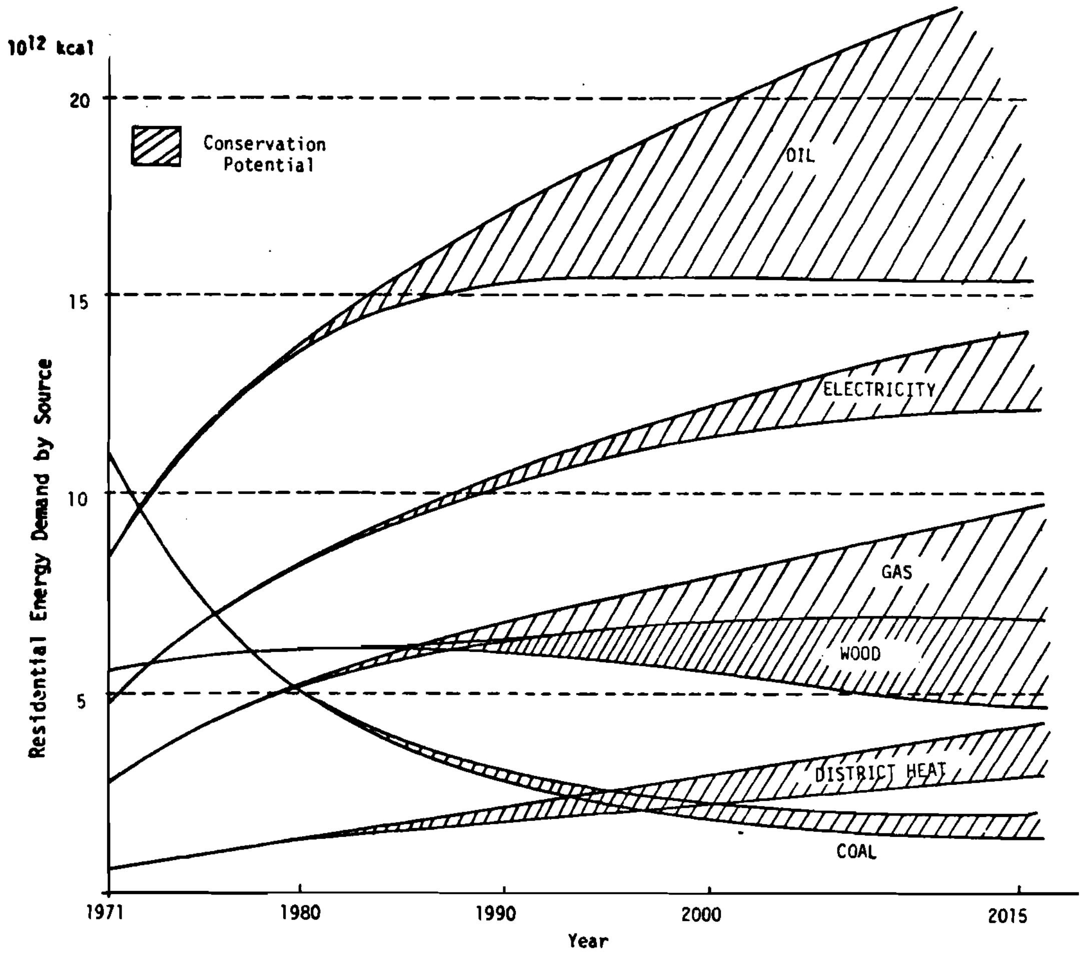

Figure 17 Potential Savings by Insulation Measures & Efficiency Improvements for Space Heating by Energy Type

4.2 Unconventional Energy (Solar, Heat Pumps)

The impact of alternative energy sources has been studied in terms of a sensitivity study for the Conservation Scenario. Clearly the results depend very much upon the boldness of the assumptions. A set of assumptions which is commonly accepted as "realistic" (50 percent of all single family homes with the appropriate back up system for space or water heating are fitted with alternative energy technology such as small scale solar systems by 2010) can substantially lower residential oil requirements in Austria. This is because it is thought that oil, which is easy to store, to transport and is network independent, will capture a big share of the single family homes as a heating energy type as long as it is available at reasonable prices, unless alternative energy types begin capturing an increasing share of the market.

There will be little difference in the results shown for overall residential electricity use in Austria if alternative energy technology is applied or not. Electricity savings gained through the use of alternative technology is balanced out by the electricity needed as energy input to the alternative energy technology (e.g. electricity driven heat pumps).

Figure 18 shows a possible market penetration curve of the new technology, the slope and the penetration limit. This function shows the assumed rate at which single family homes with the appropriate back up systems will use an alternative fuel technology. [28]

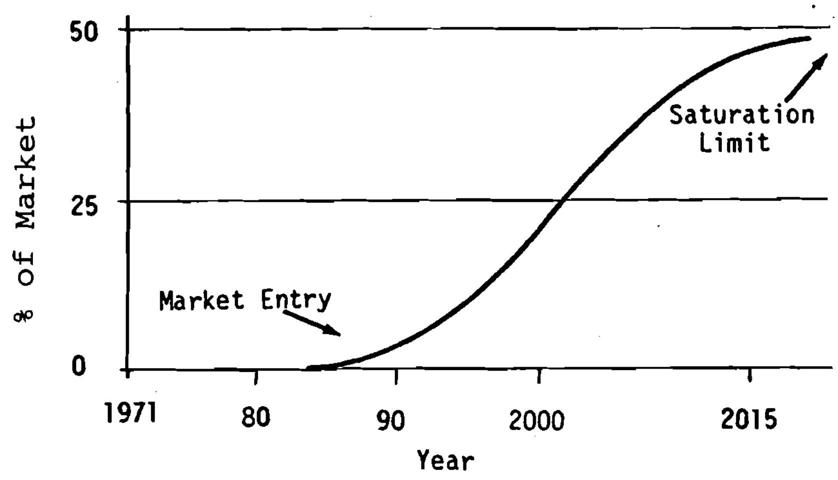

Figure 18 Market Penetration Curve for an Alternative Energy Technology

The shaded areas in Figure 19 show the potential savings from the alternative energy type technology. By 2015

28 It must be stressed that the curve pertains only to homes with characteristics appropriate for alternative technologies i.e. single family homes with the appropriate back up systems (Electricity, gas and oil central heating systems as shown in Figure 11 on page 43). Therefore 50% penetration refers only to these homes and not to the housing stock as a whole.

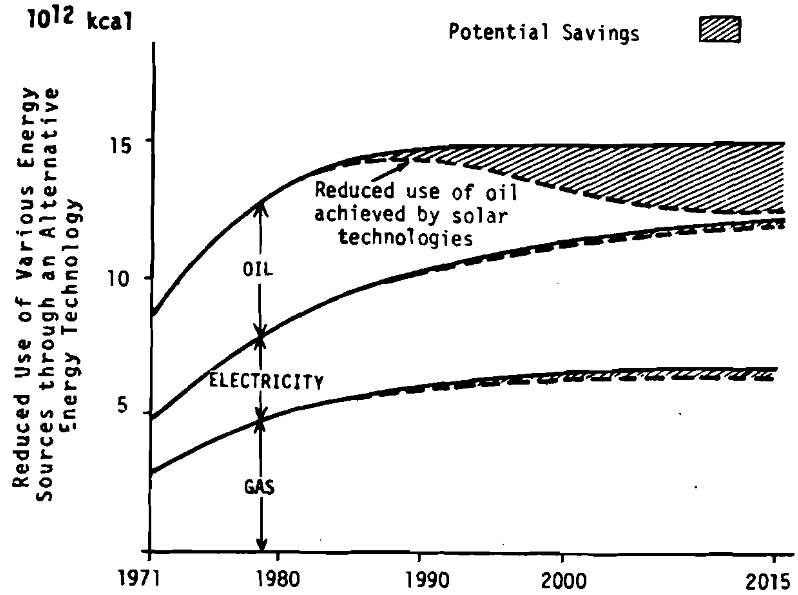

Figure 19 Potential Savings from an Alternative Energy Technology

240.000 single family homes (8% of all homes, 18% of all single family homes) are assumed to have solar space heating, and 540.000 (17% of all homes, 41% of single family homes) solar water heating. Solar space heating is assumed to replace 60% of the annual heating requirements, and solar water heating 70% of the annual energy use for water heating. 7% of the total residential energy demand would be provided by solar energy under these assumption: This use of solar energy would relieve 17% of residential oil requirements by 2015. (30% of the 1971 residential oil requirements).

5 Example of Overall Scenario Results

The relative importance of major end-use categories in determining residential energy demand is shown for the Austrian scenario and compared with the two sensitivity studies in Table 8.

Table 8 Percentage of End-Uses in Total Residential Energy Demand

		Conservation Scenario					
		Results		Insulation Sensitivity		Solar Sensitivity	
	1971	2000	2015	2000	2015	2000	2015
Space heating	~ 82%	73%	69%	78%	77%	63%	60%
	per cent of total residential energy consumption						
increase	100%	119%	113%	151%	174%	119%	114%
Water heating	~ 7%	11%	12%	9%	9%	11%	12%
	per cent of total residential energy consumption						
increase	100%	207%	234%	207%	234%	207%	204%
Household Appliances	~ 11%	16%	19%	13%	14%	16%	18%
	per cent of total residential energy consumption						
increase	100%	190%	223%	190%	223%	190%	223%

The high fraction of demand due to space heating shows that increases in floor space per capita and heat losses due to insufficient insulation are the most important factors in determining the total amount of energy consumed by the residential sector. The increase in floorspace per capita is due to the assumed decline in family size, and to a greater extent to the size of NEW HOMES. Especially the impact of bigger NEW HOMES could be balanced off by improved insulation of construction. It can be argued that keeping the size of NEW HOMES low could add momentum to the decline of family size and thus have an increasing effect upon residential energy consumption. Even with a strict conservation policy as applied in the conservation scenario, space heating will remain the dominant end-use category in the residential sector.

The increasing shares of water heating and secondary appliances in Austria points at the inherently greater dynamic of these end use groups compared to space heating. The number of Austrian homes fitted with a bath or a shower doubled between 1961 and 1971 and tripled between 1961 and 1977. Approximately by 1990 all homes are assumed to be fitted with a bath or a shower. The increasing share of household appliances is due not to increased consumption per appliance, but the increasing fraction of homes acquiring them. Their increasing share of end use energy for the conservation scenario is explained by the fact that the assumed vigorous insulation policies have not been matched with equally vigorous policies for reduced energy use of household appliances (though moderate saturation level and saturation speeds were assumed). This indicates that a policy aiming at less energy use for secondary appliances per hour of use would be necessary to complement a strict conservation policy.

The residential sector of Austria is one area where the demand for fossil energy types could be decreased (without sacrificing comfort) by appropriate policies.

Figure 20 shows the residential demand by energy type for Austria for the Conservation Scenario and the sensitivity studies, comparing historical 1971 data with the results for the 1990 and 2015.

For 1990 and 2015, the percentage of total residential demand for each energy source is essentially the same. This is because the energy type mix for space and water heating is kept constant. By 2015, roughly 51% of the residential energy demand is for petroleum and gases, which must be imported. With the expected decline in fossil energy type availability, this high percentage of demand, even in a conservation Scenario, is a potential problem.

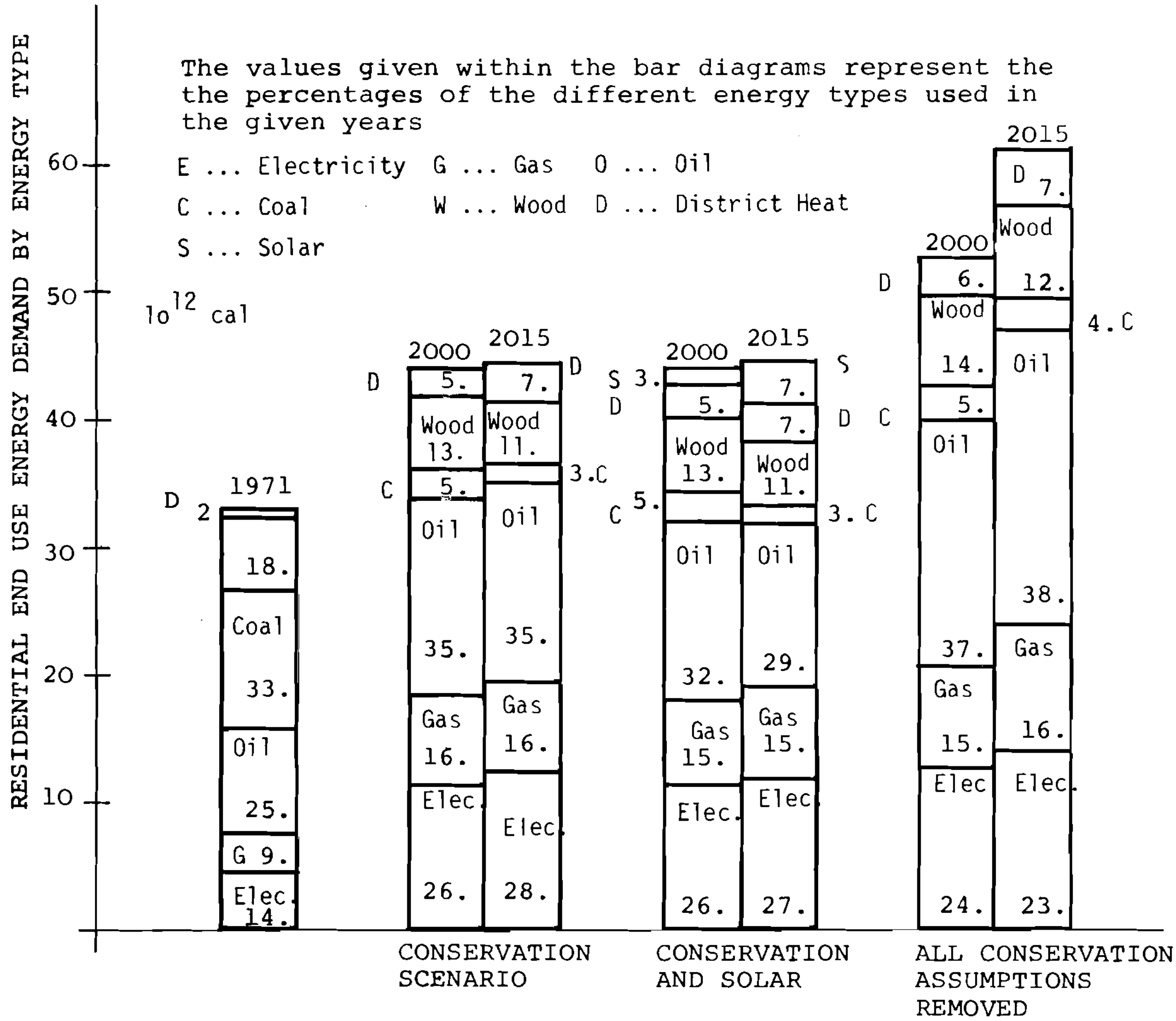

Figure 20 Residential End Use Energy Demand by Energy Type

6 Concluding Observations

In order to be able to answer the specific energy questions that decision makers are concerned with, a high degree of disaggregation has been applied in REUMA. Thus the data requirements of the model are extensive. The major strength of the residential model is that it provides a systematic framework for residential energy consumption, based upon physical characteristics, e.g. heat loss and floorspace, to analyze policy issues and alternative futures. The model has been applied to a wide range of questions related to residential energy requirements and the environment. At the present stage of development, energy prices and other economic variables are not included in the model; they must be treated in an implicit manner or in supplementary analysis.

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APPENDIX

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ERRATA

Figure 2, page 11: replace 10^{12} cal by 10^{12} kcal for the vertical axis.

Figure 20, page 65: as above.

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