ELSEVIER

PII: S0301-4215(98)00054-8

Energy Policy. Vol. 26, No. 15, pp. 1153–1165, 1998

0301-4215/98 $ - see front matter

Energy planning in urban historical centres A methodological approach with a case-study

A Gomes Martins
Department of Electrical Engineering, Faculty of Science and Technology of the University of Coimbra Portugal, Polo 2, Pinhal de Marrocos, 3030 Coimbra, Portugal

Rui Figueiredo
DEM, University of Coimbra, Coimbra, Portugal

Dulce Coelho
ISEC, Coimbra Polytechnic Institute, Coimbra, Portugal

José Luís de Sousa
EST, Setúbal Polytechnic Institute - Setúbal, Portugal

The paper aims at the presentation of a methodology for energy planning in urban historical centres, using the historical centre of Coimbra, an old Portuguese city, for illustrating purposes. The paper starts with a general perspective of the problems associated with planning activities in historical centres. It describes a methodological approach and general procedures used in the formulation of a mid-term energy plan and presents its main prospective items – identification of objectives and recommended measures, and evaluation of measures' impacts. It also draws a picture of the standard steps to be given and procedures to be adopted in similar plans. It then presents the formulation of the mid-term energy plan for the historical centre of Coimbra. Difficulties found and anticipated are listed and directions for circumventing them and for future methodology improvements are also presented. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Energy planning; Historical centres; Environmental impact

Introduction

A historical centre (HC) can be defined as an older urban cluster with homogeneous physical and sociocultural features (Gallo, 1993). It is structurally different from the industrial city and has a profound value for society in all countries. The protection of HCs has to take into account the demands of contemporary life, but it needs to assure the preservation of cultural and architectural values. The best guarantee of the conservation of HC areas lies in the integration of these areas into the life of the city, and the full involvement of the residents in the process of conservation.

Actions to bring about the protection of HC must be integrated into regional and urban planning initiatives. Interventions in HC require, independently of their nature, rather special skills which are not common in the building and in the service industries, used to standardised modern technologies. The need to deal with traditional materials, to understand ancient building practices and to respect historically and artistically valuable manufacts requires special skill; any large-scale program of intervention in HC should include specialised training to form suitable personnel.

Historical centres present special features from the energy point of view, which are common for cities which are otherwise quite different, namely characterised by the lack of contemporary comforts like heating in all living spaces.

Several different kinds of difficulties to the implementation of an energy plan can be anticipated.

In general, in most European meridional countries people are not educated for energy and environment awareness, town administrators not being an exception. This has major consequences that will show mainly in the implementation phase of energy plans for urban perimeters, where a strong commitment of several agents, predominantly of local authorities, is needed if the targets are to be attained. Other objective reasons exist for this lack of awareness as, for instance, strong financial constraints existing at the local administration in general, and still many basic population needs to be satisfied, that naturally are assigned high priority in municipal activities.

On the other hand, planning for energy efficiency is still expected to bring significant reductions of energy consumption, regardless of the particular situation of the region for which the plan is prepared. People's comfort is seldom an addressed issue at the planning level, which is particularly inadequate when discomfort is an evidence. This is very important in the residential sector, and the perspective that conservation in offices and commerce should help obtaining better comfort conditions for the residents may be difficult to impose. Furthermore, this means adopting policies for indirect welfare redistribution as, for instance strongly subsidizing economically feeble tenants in order to increase both comfort and efficiency.

The lack of demand-side management (DSM) policies assumed by electric utilities themselves or as a government mandate is a drawback for increasing efficiency. This is a more frequent situation than the reverse and where there are no stimuli, consumers tend to rest at their present status. This means lost opportunities of demand reduction and of more efficient use of resources, be it at generation, transmission or distribution level.

Energy planning for efficiency and environment protection is, however, a cause for which it is easier to gain local authorities and organizations than it was some years ago. General awareness for this type of problems has grown lately, creating favourable conditions for launching appropriate programmes, complemented by regulations, that can play a major role in promoting systematic planning activities. The extension of this concept to urban areas, including historical centres as special locations is a must, be it conducted mainly by efficiency criteria or by environmental concerns. In the 1990s, initiatives such as the Aalborg Charter, in 1994, or the Lisboa Action Plan, in 1996, are actual examples of concerted international efforts towards the acomplishment of the Agenda 21 and the Habitat Agenda, under the sign of sustainable development of cities.

The paper starts by presenting a proposal of a methodological approach and general procedures to be used in the formulation of mid-term energy plans (MEP) for historical centres (HC) and presents the main prospective items of such plans – identification of objectives and recommended measures and evaluation of measures' impacts, also anticipating potentially helpful developments of the involved procedures. Then it presents the case-study of the historical centre of Coimbra, before some concluding remarks.

Methodology approach

Similarly to other urban energy plans (Commune di Catania, 1997), the aim of a MEP for a HC is to reduce energy consumption and air pollution levels and to improve the bioclimatic conditions and general living comfort in the area while at the same time respecting architectural traditions and aesthetic requirements.

In the preparation of a MEP a minimum list of items must be followed, namely including a detailed knowledge of the existing situation (eg establishing a base year information), the definition of the long-term perspectives, a clear picture of the objectives to be attained and the measures to be adopted, as well as the evaluation of their corresponding potential, cost effectiveness and impacts, the definition of an implementation schedule and of an action guide for the implementation phase.

Establishing a base year information

The first element in establishing a base year information is to get, in a near exhaustive way, information on energy consumed within the HC boundary, which can be obtained from a number of sources: electricity, gas and fuel oil suppliers; electric load diagrams at appropriate nodes of the electricity network; several entities and the consumers themselves.

Characterising the structure of demand for the various energy sources requires a cross-checking of data from both sides: demand and supply. For a HC it may be acceptable to cover exhaustively the biggest consumers for they are usually a small number when compared to the rest. For the residential sector and most of the service sector, some form of sampling is required. It may be based on the assumption of approximately normal statistical distributions of energy consumption, which are compatible with random sampling. Also, standard questionnaires both for consumers and suppliers are needed, together with some form of computer-based storage of data. The tools to be used here must provide some means of interactively ascertained values in order that supply and demand data balance each other. Adjustments based on good judgement must be made nevertheless producing results very rapidly if conveniently helped by the computer.

Data acquisition can also be performed to obtain electric load patterns of the low voltage grid. Transformer stations may reveal to be a good choice, eventually complemented with data acquisition of some finer detail

– a feeder supplying a residential area, for example. This implies the use of specific instrumentation and software. Load patterns contain valuable information that the simple accumulated values of energy consumption are unable to provide. Among other things, with the help of load diagrams it is possible to establish average patterns of load demand, to identify maximum demand values and their time of occurrence, to assess the effectiveness of the use given to the capacity resources available, to better evaluate the potential of DSM strategies. General strategies of peak clipping, load shifting and strategic conservation may reveal to be adequate and deserve attention as options for the implementation of DSM programs.

In order not to skip over the potential of passive solar techniques for energy saving and environmental protection, also a detailed knowledge of the characteristics of the building stock is required.

The second element in establishing a base year information is to estimate the environmental impact of the specific forms and amounts of energy used (see section evaluation of potential and cost effectiveness of measures).

Defining targets and measures

Defining targets and measures is typically a stage where familiarity with conservation opportunities and good judgement play a major role. Check-lists may help but they are hardly necessary when the team elaborating the Plan has experience on efficient use of energy in general. Very exhaustive and useful check-lists may be found in the literature (OCDE,1995; O'Callaghan, 1993). Definition of targets has to be iterated with the following stage of defining an implementation schedule. Overall effects of the measures defined in the Plan may not lead necessarily to the exact targets defined, which must be revised when a realistic schedule is prepared.

The definition of long-term objectives can be much influenced by the existence of low-income residents who experience poor comfort levels. This is a common situation in many HC, where the lack of urban renovation projects usually leads to the existence of old retired tenants living, as a rule, on low-value pensions. If one might consider that retired people tend to consume more energy due to longer permanence periods at home, their welfare status normally acts on the opposite sense (Yamasaki and Tomonaga, 1997).

Under these circumstances, comfort conditions should be addressed in the formulation of the MEP, in the name of social equity, without disregarding sustainable urban development. Thence, when necessary, a combination of strategic conservation in the non-residential sectors and a conservative consumption growth in the residential sector may be envisaged (Rabl and Gellings, 1989), in order to make possible the rising of the *per capita* energy consumption value to a level corresponding to better comfort conditions and simultaneously confining emissions.

However, this becomes a challenge for the indispensable cost-effectiveness analysis. One effective way of circumventing the major difficulties is to set the reference case for the comparison by assigning to it the same level of energy services obtained at the end of the planning horizon with the implementation of the MEP, but valued according to a non-conservationist growth of consumption (Boardman, 1987).

It should also be stressed that in order to raise the comfort level in the residential sector it is usually necessary to install new equipment, which will demand some level of funding according to the social and economic conditions prevailing in the majority of the population. On a basis of equity, this investment should be predominantly directed to those people with less economic capability, and it is convenient to have in mind that solutions of this nature always demand political decisions.

The plan must suggest a catalogue of measures for different areas, where applicable. They can be used to actually improve comfort levels in the residential sector and to limit energy consumption growth in the other sectors, as stated before. There are, however, many obstacles which cannot be assigned to technical problems but result from different interests, political and personal disagreements, lack of effective communication or unfavourable general economic conditions.

Also, regulations directed at the preservation of historic and architectural values may possibly introduce strong restrictions to the adoption of solar energy collection devices that would otherwise spare appreciable amounts of electricity or fossil fuels. Passive solar techniques, on the other hand, are usually not so strongly limited, provided that facades are not altered.

Evaluation of potential and cost effectiveness of measures

The notion of potential of application of a measure corresponds here to the amount of yearly energy consumption that the introduction of that specific measure will change.

In the particular case of those measures which may lead to an increase of the *per capita* consumption, the concept of potential corresponds to the global growth of consumption projected for each measure.

Evaluation of potential and cost effectiveness of measures demands the use of a tool that allows performing 'what–if' analysis. Different penetration levels for the measures lead to different impacts and different solutions to the same problem may also reveal different 'cost–benefit' values. Several spreadsheets can be used, which reveal to be a very handy tool for the purpose. A previous activity of gathering market availability of technical solutions and prices is essential and must be maintained in an efficiently organised filing arrangement for easy reference of the working team.

Cost effectiveness for each measure should be evaluated and its calculation is generally done according to the well-known equation:

cost effectiveness = cost − benefit

The term 'cost' can be calculated on the basis of market prices and should include: investment costs, repair and maintenance costs, operational costs and external costs of fuel combustion.

The term 'benefit', also based in market prices, should include: avoided investment costs, avoided repair and maintenance costs, avoided operational costs and avoided external costs of electricity generation.

Environmental impact evaluation must be included in the MEP. As the environmental externalities impose costs on society, they must be quantified and included as monetized values for the sake of simplicity (Birner *et al*, 1993). To determine the monitized value of an externality the effects caused by a resource use must be accounted, such as the number of health effects, reduction in visibility, materials and crop damages, or impacts on ecosystems, and then estimating a cost value for each unit of each effect. The effects should then be combined with their cost values to determine an externality cost.

For a thorough assessment of the MEP, besides a list of measures, a cost-effectiveness analysis and an evaluation of the environmental impacts, it is necessary to have a preview of the Plan's development and of the effects that will gradually be observed as the implementation proceeds.

Implementation schedule

The definition of an implementation schedule is a critical activity because its result is the reference for implementation: it contains information on the starting time and pace of implementation of each measure, also quantifying the desired penetration and expected impacts in terms of energy consumption and environment. It must comply with the defined targets and with existing regulations, and also with the expected availability of certain planned infrastructures that may be important for the Plan's implementation, as well as with the availability of possible funding programmes. If possible, it should also provide information on global investment needed and its phasing. A set of spreadsheets organised as a coherent 'workbook' may be used for iteratively defining an acceptable schedule. There are here definite chances of improvement, as decision–support is crucial at this phase. Criteria can be set forward to evaluate possible planning solutions, mainly based on the targets defined previously, and constraints can be formulated in order to comply with different kinds of limitations to be observed. All this is usually accomplished in an empirically driven way, leading to a solution Plan about which there is no possible guarantee that it corresponds to some 'best' solution – better defined as non-dominated solution. If a decision–support system is available, tailored for this type of problem, any plan choice based on it is a non-dominated plan, ie, it is not possible to change any variable's value without worsening the solution from the point of view of some of the criteria used.

Table 1 Identification of the main tools applicable to the various planning phases

Phase	Item	Tools
Get a picture of the present situation	Building stock characteristics	Questionnaire Data base or spreadsheet
	Energy demand characteristics	Questionnaires for supply and demand sides Data base or spreadsheet Energy auditing devices and specific software
Evaluate cost-effectiveness and potential of measures	Definition of targets and measures	Check-lists
	Evaluation of potential and cost-effectiveness of measures	Spreadsheets
Define an implementation schedule		"Workbook"(set of spreadsheets) or, best, a decision-support system
Define an action guide for the implementation phase		

Action guide

Defining an action guide for the implementation phase deals with a great number of issues which are generally independent of the specific case (historical centre) to be addressed. The main issues are related to the application of project management techniques to the particular case of the implementation of an energy plan to a region where actors are very likely of similar nature and categories in a vast majority of the existing historical urban centres. There is no special opportunity for automating the process of defining the action guide. This one may be simply adapted to the specific aspects of each new case.

Table 1 presents the main phases of the preparation of a Plan and the main tools applicable to the various planning phases.

The case-study of the historical centre of Coimbra

The mid-term energy plan (MEP) of the city of Coimbra, Portugal (Martins *et al*, 1995) was a goal of the REBUILD Programme, in which the Town Councils of several European cities were involved.

The HC of Coimbra, as considered for the MEP, covers a surface of about 600.000 m^2. There are no industrial activities inside the HC, except for a few small bakeries that hardly may be considered as industrial installations justifying a specific treatment as such.

Hence, besides the residential sector, the main uses for buildings are commercial stores, banks, insurance companies, health care institutions, the university, central administration offices, Town Hall offices, hotels and various other private offices.

As in other ancient towns, the residential sector in the HC has been receding along the years together with the progressive transformation of houses into offices and stores. According to the most recently published data the number of inhabitants in the HC is 6293 (Instituto Nacional, 1994). On the other hand, residents are in general old aged people, mostly tenants, paying low rents and living on low incomes (mostly retirement pensions). There are some exceptions to this, namely some proprietors of single family houses and residents in some recent or refurbished apartment buildings. Hence, in spite of the moderate climate there are periods – mainly in Winter – when people live in conditions of appreciable thermal discomfort, usually associated to low-energy consumption values.

The *per capita* electricity consumption for the resident population is about 657 kWh/year, which is a sign of a low comfort level. Hence, the targets defined seek a moderate increase in comfort level in the residential sector, trying at the same time to reduce consumption in the service sector by increasing efficiency, replacing of electricity and other energy sources by gas in some final uses and through the use of renewables.

Adopted methodology

In the case of the present study there was a total absence of information or, at least, a high degree of imprecision associated to the information available in almost all the data categories. For instance, as regards to energy consumption values, data have had to be collected in a near exhaustive way, except for the smaller consumers. For the residential sector a sample has been established to give a confidence level of 90% and a precision maximum error of 10%, assuming a normal distribution of energy consumption. An extensive field work for data collection from the consumers themselves was performed, as well as many contacts with suppliers of electric energy, gas and fuel oil. Additionally, weekly load diagrams of all the transformer stations of the electricity public network have been obtained through automatic data acquisition systems.

There was a previously prepared base of information on the HC's building stock with detailed information on several items. These data have been loaded to a worksheet, which has been used for various analysis and evaluation of potential application of the measures.

A programme of formal contacts with several entities has also been implemented. Persons responsible for the smallest administrative zones ('freguesias') of the HC, big consumers, regulatory agents, energy suppliers, associations of citizens, professional and designer associations have been contacted in order to obtain opinions on the measures proposed for the MEP. In a second phase, fewer entities were selected to increase the team's awareness of the main barriers/problems and of the general receptivity to the measures proposed. For the preparation of the MEP's schedule of implementation some computer based tools have been created, based on a workbook, that allowed some iterations and 'what–if'-type analysis to be performed. This analysis could be made in a practical way since the consequences of any alteration were automatically evaluated, both for emissions and energy demand, for the whole planning horizon and, then, the conformity with the plan objectives could be readily verified.

For the evaluation of the environmental impact of measures affecting the use of electricity, variations in the use of electric energy caused by each measure (when applicable) were quantified and then monetized, allowing cost-effectiveness analysis to be performed in currency values, including environmental externalities. A custom procedure has been considered, which took into account the characteristics of the Portuguese electric production system and, accordingly, the source mix used to meet demand has been used to quantify emissions. Some indexes from the literature have been used to monetize emissions (Ottinger *et al*, 1991; Wood, 1992 ; Weaver *et al*, 1992). Furthermore, in the cases where the implementation of measures leads to increased direct fuel burning (always gas or biomass) or fuel replacement, the balance was found between emissions avoided remotely and increased emissions at the local level, the corresponding monetization being performed according to the procedure described above. In general, emissions were quantified in mass flow units. In the cost-effectiveness analysis process the calculations were performed on a per-unit basis, ie, for a single device/system, the impacts being assessed through simple extrapolations to the estimated penetration levels for each measure. The proposed measures were chosen accordingly to their estimated potential of penetration. Some others were not deliberately considered, since the adoption of active policies of DSM does not seem likely to happen in the near future. Load shifting, for example, could have a significant effect if the present double rate option of the tariff system was actively promoted, which is not the case. In fact, several factors may help understanding this particular *efficiency gap* (Weber, 1997) situation. Firstly, a traditional lack of utility 'culture' on energy efficiency promotion. Besides, a favourable climate, in general, adds to the effect of a low *per capita* consumption. Some utility initiatives to promote energy efficiency have never been evaluated and, thence, never have been considered as part of the company's corporate strategy (Martins and Jorge, 1995). Finally, only very recently the Portuguese office for regulation has prepared a tariff regulation where some provisional form of DSM funding is considered.

Table 2 Number of consumers in the different sectors

Sector	N° of consumers
Residential	2738
Hotels	28
Restaurants	150
Banks	18
Clinics	2
Pubic buildings	62
Commerce	680

Per capita electricity consumption-657 kWh/year

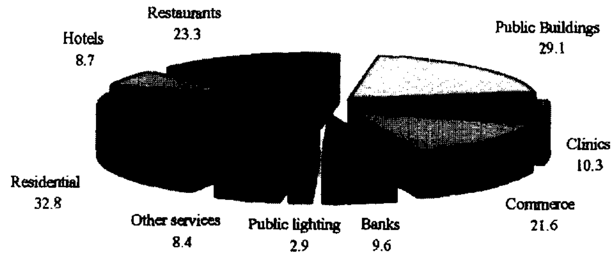

Figure 1 Annual energy consumption values, in *TJ*, of each sector

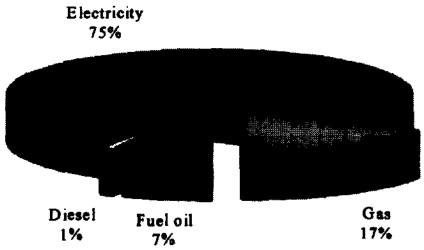

Figure 2 Relative importance of the different energy sources used in the HC

Overview of energy use

It is possible to consider two relatively different regions within Coimbra's HC. One is a more or less flat region where there is a predominance of non-residential uses of the buildings. The second is a hill where the oldest and the greatest part of the university buildings are located and, apart from these, there is a predominance of the residential sector. Most of the buildings are very old and degraded and the residents have in general a quite feeble economic situation.

The tertiary sector is the most important field of activity in the HC, mainly because of the university. Hotels, restaurants, banks, clinics, public buildings (which include the university buildings, city properties and other public services) and commerce are the economic and social activities responsible for the biggest amount of energy consumption in the HC.

In Table 2 the number of energy consumers of the different studied sectors, are presented.

Figure 1 depicts annual energy consumption values by the different sectors. Besides the sectors considered before, public lighting is included in this figure, for it is also an important energy consumer in the area, including street and monuments lighting.

The HC of Coimbra had in 1994 an annual energy consumption of 146.7 Tera Joule (TJ), which corresponds to approximately 62.62 kWh/m^2. The energy sources used by the HC consumers are essentially electricity (109.5 TJ), gas (25.1 TJ), fuel oil (10.6 TJ) and diesel oil (1.5 TJ).

The relative importance of the different energy sources used in the HC is represented in Figure 2.

It can be seen from the figure that electricity is the most used energy source. It represents 75% of all energy consumed. This is a very comfortable energy source to use and has been once also a cheap one (regarding the buildings' age).

Annual electricity consumption values are presented in Figure 3.

Figure 4 represents the values of annual energy consumption in public lighting in the HC. As street light consumption values are not recorded monthly, there are only four values for each year/feeder.

The types of lamps mostly used in public lighting are mercury lamps, sodium lamps and metal halide lamps, depending on the functional needs of each area. Hence, streets, parks, monuments, residential and pedestrian areas are lighted with different types of lamps.

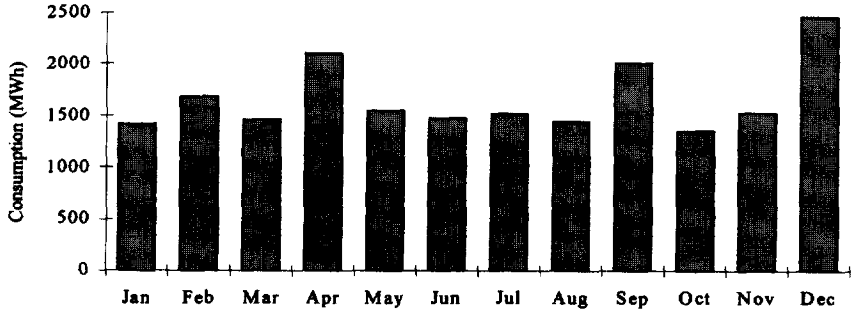

Figure 3 Annual low-voltage electricity consumption, in the HC in 1992

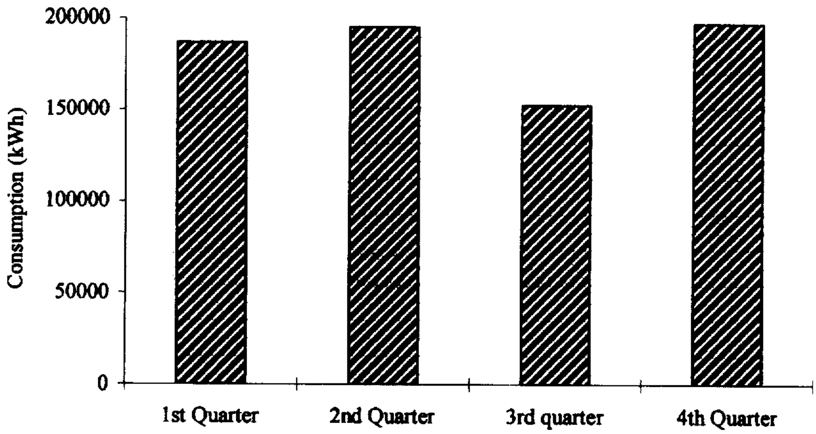

Figure 4 Energy consumption in public lighting, in the HC at 1992

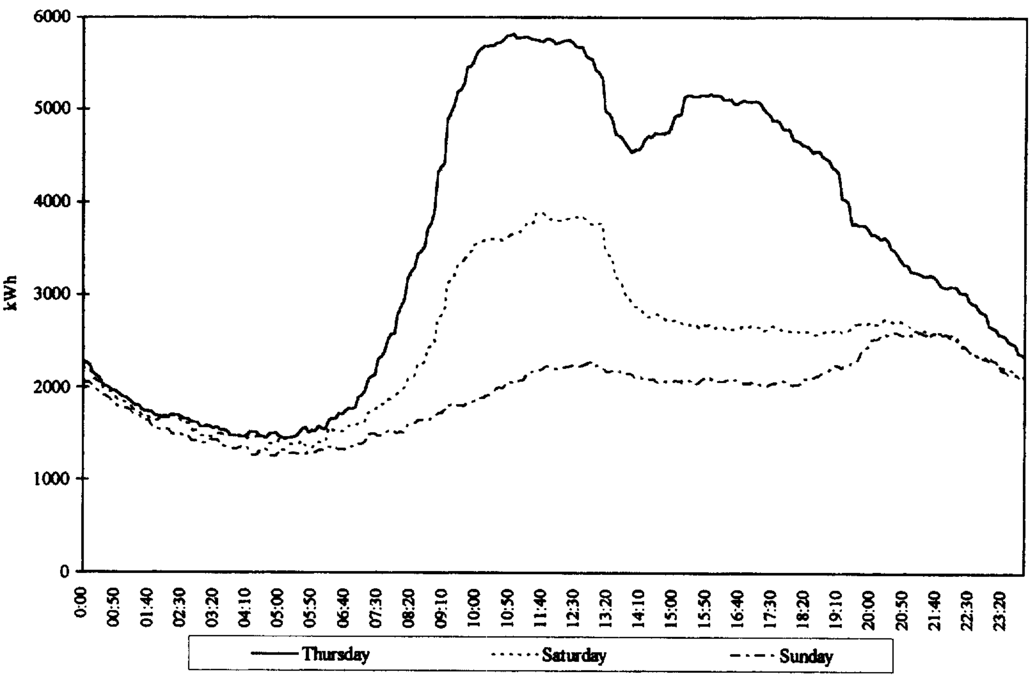

Figure 5 Global load diagrams for the three types of days

As the types of lamps used depend on the area, so does the lighting needs during the day and the time of the year. Lighting control is implemented mostly by the use of photocells and time clocks.

As electricity is the most used energy source, in Figure 5 are represented the load diagrams for the three types of days: Saturdays, Sundays and Thursdays (Thursdays have been elected as the typical working day for the study). These load diagrams were obtained by summing up all the individual histograms from the surveyed transformer stations. Data have been collected at every transformer station during a whole week in a total of 32 metering points.

Very apparent differences exist among the three diagrams. The working day has very well-defined high demand periods (between 10:00 and 13:00 and between 15:30 and 18:00), corresponding to a high economic activity level – namely commerce and the rest of the tertiary sector. On Saturday a maximum demand period is visible (from 9:30 to 13:30), probably due to commercial activity, but smaller than in working days. Sunday diagram has a much smoother aspect, as it should be expected.

Power values at valley periods are very similar at all times, probably giving evidence to public lighting consumption, which must not be very different from one day to another.

Load factors are 0.60 on Saturday, 0.68 on Sunday and 0.57 on working days. This latter is appreciably low, raising the possibility of a good potential for load shape

Table 3 Numerical indices obtained from the load diagrams

	Working day	Saturday	Sunday
Total installed power (kW)	16070.0	16070.0	16070.0
Total average power (kW)	3546.9	2459.5	1934.9
Total maximum demand (kW)	5816.5	4279.1	2819.0
Total consumption (kWh)	84684.4	58740.2	46466.8
Average demand utilisation (h)	13.67	14.32	16.35
Average installed power utilisation (h)	5.85	4.20	3.34
Average load factor	0.57	0.60	0.68
Diversity factor	1.07	1.10	1.08

alterations in order to improve the rational use of the available resources in the distribution network.

In Table 3 some global characterisation indices are presented, that can be obtained from the load diagrams.

Solar energy availability

The possibility of introduction of solar collectors in the HC of Coimbra has been considered. Obviously this particular domain of intervention puts some restrictions to the use of such devices, and as a general rule only top-roof integrated collectors should be installed in order to preserve the ancient character of this part of town. This is a rather severe restriction as the inclination of the roofs in general does not exceed 30° which is a relatively small value for solar applications at the latitude of Coimbra (Duffie and Beckman, 1991). On the other hand, buildings presenting a very marked historical or architectural interest are excluded from this analysis, and also those which correspond to locations that are inadequate from a solar energy point of view (all the buildings placed in the northern side of the hill, for instance). Nevertheless, the relatively high levels of solar energy available in the region of Coimbra, which are represented in Figure 6, make this measure apparently a very attractive one.

Table 4 Electricity consumption as shares of thermal power plants production in Portugal[a]

Unit type	Production MWh	%
Coal-fired	7473.2	44.4
Fuel oil-fired	9341.5	55.5
Diesel oil-fired	16.8	0.1

[a] EDP, ed, *Technical Report* (in Portuguese), EDP, 1992.

Table 5 Emission coefficients for each pollutant by unit type

Unit type	SO_2 g/kWh	NO_X g/kWh	CO_2 g/kWh
Coal	6.6	2.9	840
Fuel oil	16.5	2.3	770
Diesel oil	2.4	1.6	1200

Pollutant emissions

In this study a distinction between indirect and direct emissions has been made. Indirect emissions are those associated with electricity production from thermal power plants and consequently associated with electricity consumption. On the other hand, direct emissions are associated with local fuel combustion.

Annual electricity consumption in the historical centre is 28 052.5 MWh (1994), where around 60% are covered by fossil fuel-fired generation, which corresponds to 16 831.5 MWh.

In order to assess the importance of the indirectly produced emissions due to electricity consumption in the HC, the shares of fossil fuel types used in thermal power stations have been used (cf. Table 4).

According to the average emissions resulting from the combustion of the fuels used in the various thermal power stations in Portugal (cf. Table 5), it has been possible to assess the average emissions due to each generated MWh: 0.012 ton (SO_2); 0.0026 ton (NO_X); 0.8105 ton (CO_2).

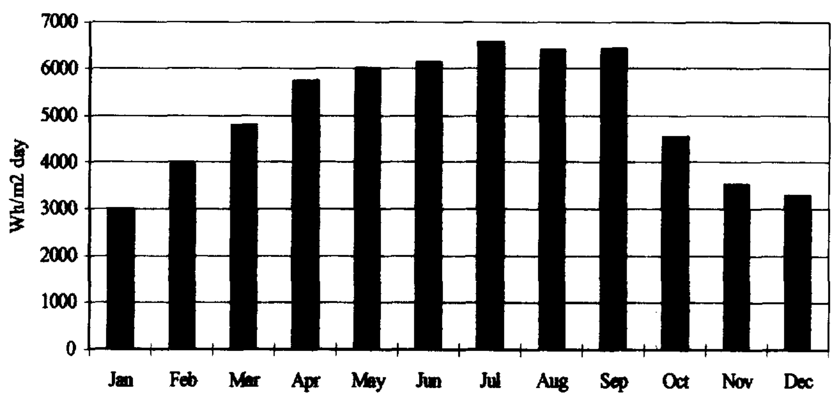

Figure 6 Global solar energy incident on a south facing 30° tilted surface in the region of Coimbra

Table 6 Consumption and emission coefficients for each pollutant by fuel type[a]

Fuel type	SO_2 ton/ton	NO_X ton/ton	CO_2 ton/ton	Consumption ton/year
Propane and Butane gas	—	0.0023	3.0440	489.82
Diesel oil	0.0059	0.0475	3.1520	31.40
Fuel oil	0.0430	0.0072	3.1200	242.30
Wood	—	0.0016	—	—

[a] CCRC, ed, *PER - Energy Plan for the Centre Region* (in Portuguese), CCRC, 1993.

Table 7 Relative importance of indirect and direct emission

Pollutant	Total emissions ton/year	Indirect (electricity) ton/year	%	Direct ton/year	%
SO_2	212.58	201.96	95.0	10.62	5.0
NO_X	48.11	43.76	90.9	4.35	9.1
CO_2	16057.40	13708.60	85.4	2348.80	14.6

The fuels that are most commonly used in the HC in local direct burning applications are listed in Table 6, together with their respective per unit emissions and fuel consumption values in the HC.

It has been considered that wood used as fuel gives no net emissions of carbon dioxide. This is due to the fact that the carbon dioxide arising from the combustion of biomass would in any case be released during the natural decomposition of the biomass.

In Table 7 the amounts of indirect, direct and total present emission values due to the HC are presented, for each pollutant considered.

Considering the upper bound levels of emissions imposed for Portugal by the European Union it was possible to assess the corresponding limits for the emissions of the HC, which have been in 1994, of about 215 ton of SO_2 and 59.4 ton of NO_X. These limits correspond, respectively, to 106.5 and 135.7% of present values, which means that electricity consumption in the HC may increase 6.5% without violating the limits imposed for the levels of pollutant emissions.

Planning horizon and general objectives

The planning horizon has been defined as the ten-year period between 1996 and 2005.

In a general way, one can assume that the main objective of the Plan is to provide acceptable comfort conditions in the buildings of the historical centre in order to avoid the gradual decreasing of the number of its inhabitants and its corresponding replacement by commerce and other services.

It is apparent from Figure 1 and Table 2 that, although residential consumers represent nearly 75% of the total number, their consumption is of the same order of magnitude of the consumption of the public buildings (and not very different from the energy demands of restaurants and commerce). This fact justifies the strategy adopted, which admits an increase in human comfort in the residential sector by means of a necessary (and inevitable) growth of consumption in this sector, which will be compensated, at least in part, by energy savings in the other sectors.

Hence two different specific objectives have been defined.

On one hand, according to the need of raising comfort level in the residential sector, *per capita* energy consumption should increase 10% to become approximately 1470 kWh in 2005.

On the other hand, as a second objective, emissions in 2005 should be limited to 1994 values. This actually means that emissions will be lower than the limits issued by the EU for 2003. The evolution of the overall energy consumption of the HC must comply with this objective.

Recommended measures

This study suggests a range of measures for different areas. They can be used to improve confort levels in the residential sector and to decrease energy consumption in the other sectors.

The measures presented are not independent and mutually exclusive in several cases, and can be grouped in three main categories: fuel switching, efficiency improvement and installation of equipment to increase comfort level in the residential sector.

The first group includes electricity replacement by gas for cooking, water and space heating in the residential sector and for space heating in the non-residential sector. It also includes the replacement of diesel oil and fuel oil by gas for water and space heating in the non-residential sector and electricity replacement by biomass for space heating in the residential sector.

Efficiency improvement involves the installation of built-in fireplaces replacing conventional fireplaces, technology replacement for public and interior lighting and thermal quality improvement of the buildings' external envelope by imposing more conservative coefficients.

In the third group are included the installation of gas-fired equipment for domestic hot water production and the use of wood stoves for space heating in the residential sector.

Although some preliminary calculations have shown that it was possible to collect considerable amounts of solar energy in the HC, the high investment costs, the lack of financial support for the implementation of this technique in the residential sector and the relatively low level of domestic hot water consumption in the HC justify the exclusion of solar collectors from the recommended measures.

Cost-effectiveness analysis

The cost effectiveness for each measure has been evaluated and calculated from the difference between cost and

Table 8 Cost-effectiveness values by measure

Measures	Cost-effectiveness (ECU)
Installation of woodstoves	54.480
Wood stoves replacing electric heaters	−57.690
Installation of built-in fireplaces	−46.220
Gas replacing electricity for cooking	−53.590
Gas repl.elect. for domestic water heating	−27.230
Gas repl. elect. for residential space heating	−28.300
Gas repl. elect. for non-resid. space heating	variable (negative values)
Gas replacing diesel oil	−13409.030
Gas replacing fuel oil	variable (negative values)
Techn.. replac. for residential lighting	−5.120
Tech. replac. for commercial lighting	−4.140
Tech. replac. for public lighting	variable (negative values)
Ther.quality improv. of build. envelope	−0.840
Installation of gas water heaters	129.410

benefit. Several assumptions and data used for the cost-effectiveness evaluation are as follows (Direção Geral, 1989):

Energy used for heating per collective household	4.54 GJ/yr
Energy used for hot water per inhabitant	2.27 GJ/yr
Energy used for cooking per household	2.72 GJ/yr
Average number of inhabitants per household	2.3
Global number of hours of operation for public lighting	4100 h/yr
Global number of hours of operation in the commercial sector	2288 h/yr
Global number of hours of operation in the residential sector	1460 h/yr

To evaluate the cost effectiveness of each measure, environmental costs due to the use of the various energy sources were included. In order to calculate environmental costs, emission coefficients are multiplied by the estimated costs of pollutants' externalities.

The cost effectiveness of each measure to be adopted is presented in Table 8.

It is interesting to note that, as it was expected, the measures elected to increase the comfort level in the residential sector present a positive value.

Potential of application of the measures

To assess the potential of each measure, knowledge of the present situation in the HC is necessary. The contacts made with several entities, referred before, have also been very useful.

As a general rule, all measures that have a negative cost-effectiveness value have been considered for implementation. Exception to this criterion are the two measures that correspond explicitly to the goal of raising comfort level in the residential sector – use of biomass for space heating and installation of gas-fired water heaters. These two measures do not have any quantified benefit in the methodology used. Hence, their cost effectiveness must have a positive value.

Implementation schedule

The scheduling exercise presented in this section uses a reference framework of options that have been considered adequate for the presentation of a methodology of scheduling and evaluation of impacts at several levels. The time scheduling of the measures in the MEP must take into account factors of different natures: social, economic, institutional, etc. From the point of view of environmental impact, for example, the ideal situation would be to achieve the full potential in the first year of the horizon.

However, several constraints such as financial limitations or a slow rate of adhesion of the several actors impose a gradual implementation. An annual percentage of achievement has been elected as the numerical representation of the pace of implementation of each measure. The percentages are the result of a compromise of several factors influencing the application of the measures proposed in the Plan. Two main factors have been considered when assigning percentages of achievement to each measure: the mid-term availability of a gas distribution network and the existence of financial incentives.

The evolution of energy consumption and of the corresponding environmental impacts is obviously influenced by the percentages defined above. If one considers strictly the effects of the measures proposed, using as a point of departure the reference year of 1995, the representation of the evolution of energy consumption in the HC may be the one depicted in Figure 7. Here, the three curves represent total consumption and non-residential consumption, to be read against the left-hand-side axis, and residential consumption to be read against the right-hand-side axis.

In Figure 7 consumption in the residential sector raises along the horizon span, in spite of the assumption that population will not grow in number. In fact, this tendency is a consequence of the option of raising the comfort level of the residents by raising the *per capita* consumption.

The second main objective consists of maintaining total emissions of the 1995 level at the end of the horizon. Hence, consumption in non-residential sectors is a function of consumption growth in the residential sector and of the level of emissions resulting from the application of the measures proposed. It should be noted that all the measures proposed for non-residential sectors are of conservative nature, giving place to a yearly energy demand in 2005 lower than in 1995. Consequently, a growth rate could not have been established *a priori* for the non-residential sectors. An allowable margin for consumption growth in non-residential sectors has been determined according to the 'credit' of emissions achieved by the application of the proposed measures for these sectors.

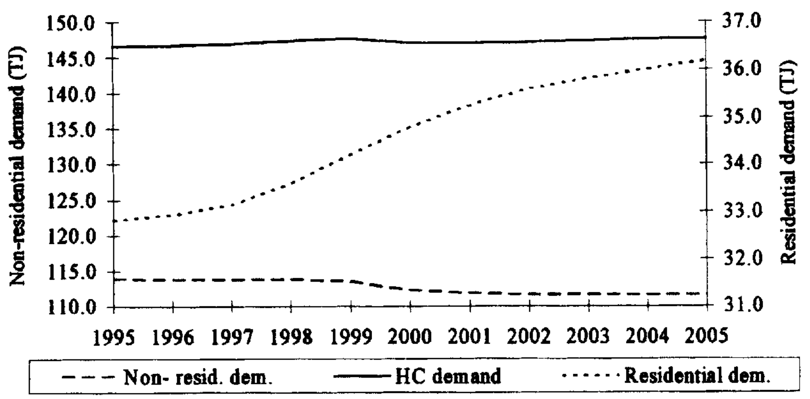

Figure 7 Energy demand trends in residential and non-residential sectors and in the HC, as a strict result of the Plan's measures

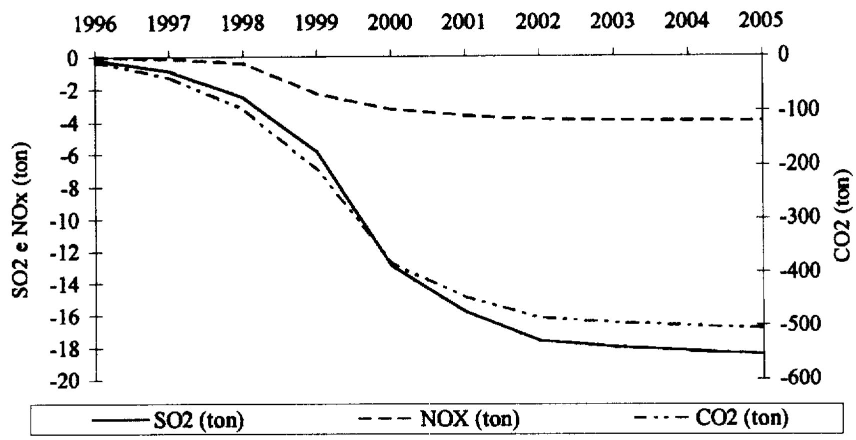

Figure 8 Accumulated variations of emissions due to the application of the proposed measures

Table 9 Energy demand and emissions at the borders of the planning horizon

	1995				2005 corrected for allowable growth			
	Consumption	SO_2 (ton)	NO_X (ton)	CO_2 (ton)	Consumption	SO_2 (ton)	NO_X (ton)	CO_2 (ton)
Non-residential total	114	182.8	41.0	13047.8	124	186.3	41.4	13994.7
Residential total	32.8	29.8	7.2	3009.6	36.2	26.2	6.8	2936.0
TOTAL	147	212.6	48.1	16057.4	160	212.5	48.2	16930.7

In Figure 8 the accumulated effects of the Plan on emissions are represented. The values corresponding to the lowest point in the curves correspond to the globally avoided emissions, that is, the emissions avoided in the last year of the horizon, when all the potential of application of all measures is fulfilled — 18.49 ton of SO_2, 3.99 ton of NO_X and 506.12 ton of CO_2. With the application of the Plan, the integral values of avoided emissions during the whole horizon are 110.41 ton of SO_2, 25.39 ton of NO_X and 3164.91 ton of CO_2.

With these results it has been then possible to compute the allowable energy demand growth in non-residential sectors, respecting the main MEP's objectives. In Figure 9 the projected allowable demand evolution for these sectors is depicted – upper curve – together with the evolution represented in Figure 7 for the same sectors – lower curve. The hatched zone between the two curves represents the difference between the two trends.

The sum of the differences between the annual allowable demand and the demand level of 1995 amounts to 53.6 TJ and the annual average demand growth rate using 1995 demand as a reference is 0.835 %. However, if one computes the sum of the differences, for each and every year, between the allowable demand and the demand resulting from the application of the Plan's measures, the result amounts to 66.9 TJ. This value is 13.3 TJ higher than the preceding one, and it may be considered as the demand-side resources that are

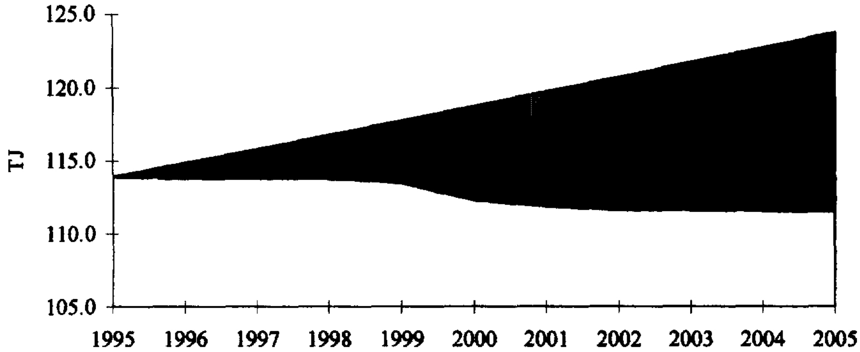

Figure 9 Allowable evolution of non-residential sectors' energy demand

potentially available respecting the constraint of freezing emissions.

In Table 9 the values of energy demand and emissions are presented both for residential and non-residential sectors, in the reference year and at the end of the horizon. Emissions are essentially the same for both years, except in the case of CO_2, where the 2005 value is 5.4% higher.

It should be noted that the allowable demand growth rate for non-residential sectors is modest, requiring a special attention during the implementation phase with the objective of managing demand efficiently.

In the course of elaboration of the energy plan for the HC of Coimbra, a set of methodologies have been set forward that revealed to be ready for re-use, adding efficacy to the planning process as they are informed by convenient computational support which has been organised in a coherent framework. However, significant improvements are possible to obtain if a specific decision-support system is prepared for this type of studies.

Conclusions

It is a well-known fact that, in general, cities are regions of high concentration of energy demand, be it in services, residential sector or transports, and consequently are characterised by high levels of direct and indirect pollutant emissions. The implementation of a general energy plan at a country level must take these aspects into consideration. On the other hand, historical centres of old cities have their own historical, social and architectural particular characteristics and special awareness is needed for the type of problems that these aspects present to the development of an energy plan.

Energy planning for efficiency and environment protection is a cause for which it is now easier to gain local authorities and organizations than it was some years ago. General awareness for this type of problems has grown lately, creating favourable conditions for lauching appropriate programmes, complemented by regulations, that can play a major role in promoting systematic planning activities.

In this work a proposal of a methodological approach is developed, to be used in the formulation of a mid-term energy plan for historical centres, together with the presentation of the case-study of the historical centre of Coimbra, an old Portuguese city.

During the preparation of the mid-term energy plan several actions have been carried out for which some systematic procedures have been prepared. The schedule imposed for the work was not compatible with a previous development of tools for automating a substantial part of the operations. Nevertheless, the set of tools and procedures prepared previously and in the course of development of the Plan became at the end a valuable framework for future similar activities. Potential exists for further improvement at several stages and for new features that have been identified as highly desirable.

The main phases of the preparation of the Plan were identified as: get a picture of the present situation, define targets and measures and evaluate their cost effectiveness and potential (a reasonable solution being proposed for the compatibilization between the necessary increase of energy consumption in the residential sector and the need of containing the local levels of emissions), define an implementation schedule and define an action guide for the implementation phase.

References

Birner, S, Chernick, P & Caverhill, E (1993). Elements of the current U.S. controversy over monetizing of externalities. *Proceedings of the ECEEE* 1993 *Summer Study – The Energy Efficiency Challenge for Europe*, Vol. 2, 233–242.

Boardman, B (1987). Energy efficiency policy and low income households, *Proceedings of the European Conference Innovation for Energy Efficiency*, Newcastle upon Tyne, UK, September 1987

Commune di Catania (1997). Integrating of renewable energies in rehabilitation schemes of cities. Urban Planning Maximizing the use of Renewable Energies, Part III, Final Report, April 1997

Direção Geral de Energia, ed (1989). Energy consumption in the domestic sector. Final Report (in Portuguese)

Duffie, J A & Beckman, W A (1991). *Solar Engineering of Thermal Processes*, 2nd Edn. Wiley, New York

Gallo, C (1993). General policies and specific strategies for the integration of renewable energies in historical centres, the case of Italy. Paper presented to *Rebuild Network 1st Symposium*, Rodi, 14–15 January

Instituto Nacional de Estatística (INE) ed (1994). *Census* 91 (in Portuguese)

Martins, A G, Figueiredo, R, Coelho, D & Sousa, J L (1995). Mid-term energy plan: Historical Centre of Coimbra, Rebuild Programme, Final Report, April 1995

Martins, A & Jorge, H (1995). Demand-side management in less developed western countries – a realistic option? *Proceedings of the 4th International Energy Efficiency and DSM Conference*, Berlim, October 1995, pp. 129–138.

O'Callaghan, P (1993). *Energy Management*. McGraw-Hill, New York.

OCDE, ed (1995). *L'Energie dans la Ville – Manuel de Bonne Gestion Locale*. Lés Edition de l'OCDE, Paris

Ottinger, R, Wooly, D, Robinson, N, Hodas, D & Bobb, S (1991). *Environmental Costs of Electricity*. Oceana Publication, IC., New York

Rabl, V A & Gellings, C W (1989). The concept of demand-side management. *Demand-Side Management and Electricity End-Use Efficiency*, NATO ASI Series E, Vol. 149, pp. 99–112.

Weaver, E M, Herman, P, Barakat & Chamberlin (1992). Environmental impact of residential fuel switching. *Proceedings of the ACEEE* 1992 *Summer Study on Energy Efficiency in Buildings* Vol. 9, pp. 223–232.

Weber, L (1997). Viewpoint. Some reflections on barriers to the efficient use of energy. *Energy Policy*, *25*(10), 833–835.

Wood, F P (1992). Analyzing the effect of including environmental externalities in utility planning. *Proceedings of the ACEEE* 1992 *Summer Study on Energy Efficiency in Buildings*, Vol. 9, 233–242.

Yamasaki, E. & Tomonaga, N (1997). Evolution of an aging society and effect on residential energy demand. *Energy Policy*, *25*(11) 903–912.