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RESEARCHES AND TECHNICAL REALISATIONS IN HOUSING AND HOUSEHOLD APPLIANCES

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RESEARCHES AND TECHNICAL REALISATIONS IN HOUSING AND HOUSEHOLD APPLIANCES

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CONTENTS

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INTRODUCTION

Several years ago the concept of energy savings was considered primarily as an important psychological and political issue, but of little quantitative significance. This was only a few percent, just a "drop in the bucket", when compared with the inevitable increase in energy consumption. Times have changed, however, and energy savings has come to be considered as a veritable "energy source". In effect, this resource is enormous, and referring only to that which is technically feasible and economically attractive, energy savings is one of the most promising energy resources of the coming decades. It is a matter of fact that an increasing number of studies in this domain indicate that the range of energy savings possibilities is between 30 and 50%, depending upon the specific application, and in some cases as much as 80%. These percentages are quite large, and if it is true that the effects of recession must also be considered, most observers claim that, in general, the recent significant decrease of world-wide oil consumption is due primarily to the implementation of savings techniques. Their potential, however, is far from being realized, and it is understood that it will be neither easily nor rapidly obtained. It will be necessary to do thorough and detailed research, to develop new technologies, to industrialize them, and to sell them on a vast market where the decision-makers are numerous, dispersed, and have very different needs, tastes, and perceptions. It will also be necessary to inform a large number of people, at all levels, about the present state-of-the-art of energy savings techniques. This is not trivial because even the specialists are often unable to confidently respond to concrete questions concerning the technicalities of energy savings. This is, in part, due to the fact that the available information is very dispersed. For a given practical application, pilot-project houses for example, it is difficult to know the references, the objectives, where the research was done and what was expected.

The purpose of this work is to present in a coherent and organized form the results of current research. It is known that the International Energy Agency (IEA) inspires a great number of research projects in many countries. These projects encompass all domains from fusion to solar energy and including heat pumps. This brief volume is intended to be of a relatively general nature.

We have attempted, by presenting the work of the IEA on energy savings, to give an overview of the results of the current research in the areas related to buildings and household appliances. We hope to conduct a future study which will be more substantial and more technical. In the course of the following chapters it will be for the reader to judge the importance and relevance of the research results. He will appreciate as well those domains which must be sponsored and are in need of further development: air quality and air renewal control, inhabitant behavior, construction standards, statistics on documented retrofits, economic attractiveness of these retrofits, etc.

In 1978 the Federal Office of Buildings published a report entitled "Energy Savings in Buildings - status, short-comings, and research priorities" (1). In the same spirit of that report, the present study addresses itself to the building professional as well as to the motivated layman who is interested in energy conservation. We will often use the term "energy conservation", which is becoming quite widely accepted, to mean the set of all measures appropriate to the most efficacious possible use of energy resources: energy savings, rational use of energy, substitution of one form of energy by another, etc.

In the first chapter, we will initially analyze the research which considers the total building as the unit entity. In the following chapter the research on the passive components (walls, windows, etc.) is presented, and in the third chapter the active components (heating and ventilation systems) are treated. The fourth chapter concerns itself with energy savings in the household appliances sector. In the fifth chapter we present the statistical and economic studies. In this chapter the energy savings measures along with their economic attractiveness and the resulting impact that they could have on the energy consumption of buildings are presented. Finally, the last chapter is dedicated to some general thoughts and recommendations. Interested readers will find in Appendix I a summary description of the IEA projects relating to energy conservation in the building sector. Appendices II and III contain an exposition of some basic notions concerning the heating of buildings and the economic aspects of energy conservation.

Finally, it is necessary to state that this document has been prepared in a relatively short time and it is thus inevitable that there are some omissions. We hope that we can improve this in the following editions and are depending upon our readers to send us their comments and make us especially aware of those pilot-studies of those research projects that we have not mentioned.

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CHAPTER I

BUILDINGS

The principal research goal in the area of buildings is to examine the feasibility of low energy consumption. This problem can be approached from a fundamental point of view by thoroughly studying the whys and hows of the energy consumption of buildings. Thus, from this perspective the first part of this chapter will consider the calculation methods involved, the instrumentation of test-buildings, the problems of air renewal, thermal comfort, construction standards, and thermal retrofit.

It is also possible to approach these problems from a more pragmatic point of view and consider that, even when all of the details are not well understood, the low energy pilot-buildings play a very important role. In general it suffices to know the specific consumption *) (before and after the renovation if it is a building retrofit), the degree-day figure for the location, the building characteristics with regard to insulation and heating and the additional expense attributed to thermal improvements. In reality, even this elementary information is often very difficult to obtain. In the second part we will briefly present some of the particularly interesting pilot-buildings and retrofit projects in Switzerland and in the world.

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*) *The specific consumption (energy index) is measured in megajoules per* m^2 *per year of heated surface area. 1000* MJ/m^2 *corresponds to about 24 kg (heating oil)/*m^2 *year. The consumption per* m^3 *is obtained by dividing by 2,5 : 10* $kg/m^2 \cong 4\ kg/m^3$ *year.*

FUNDAMENTAL PROBLEMS

A thorough understanding of the energy behavior of a building means the capability of making very exact calculations of its energy consumption by taking account of different factors such as the building characteristics, inhabitant behavior, climatic data, etc. It should be equally possible to predict the extent to which that consumption will be reduced if this or that thermal improvement measure is taken. In order to increase and develop our knowledge in these areas it is essential to place particular emphasis on studying the following problems: numerical calculation methods capable of calculating the energy behavior of a building, detailed measurements (instrumentation) in test-buildings which permit a comparison between the theoretical predictions and the reality, and problems of air renewal and thermal comfort in which the behavior of the inhabitants plays a primary role. Finally, because the application of this new knowledge poses a certain number of fundamental problems at the level of their large scale implementation, there is a need to examine certain problems related to the development of new construction standards and the thermal retrofitting of existing buildings. Each of these issues will be discussed in turn.

1) Calculation methods

The research in this domain has taken three main directions:

- The development of calculation programs that should be as complete and as close to reality as possible. These types of programs are very complex and this implies the need for highly trained personnel. Such programs could be made available to potential users by specialized institutions. Considering the expense, such a service would be justified, for example, in the case of complex buildings with air conditioning.

- The development of simplified calculation programs, which can be run on a microcomputer and which could become the principal tool of tomorrow's energy engineer. The limitations of these simplified programs should be carefully evaluated and, in particular, by comparing their results with those of more complete programs or with experimental measurements.

- The development of calculation programs whose purpose is not to calculate the consumption, but to directly establish a list of energy saving measures ordered according to their economic attractiveness.

There already exists a great number of computer programs in many countries, and the goal of one of the IEA's research projects (*Project I*) has been to collect the different programs and determine their coherence. This project enabled EMPA to install and use the Berkeley program DOE-II (2) in order to adapt it to Swiss conditions. Currently under study is the possibility of eventually making it available as a public service. This type of program is particularly suitable for complex buildings (service buildings) with ventilation and air conditioning.

The comparison of calculation programs conducted within the framework of *Project I* was principally concerned with a fictional air conditioned administration building. The operating conditions of that building have been extremely simplified: only one climate zone per floor, constant temperature both day and night, absolute air-tightness (no infiltration), no shutter movement, etc. An examination of the results indicates deviations on the order of 10 to 15% with respect to the mean for quantities such as the maximum power required for the air conditioning system or the total energy consumption. Certain initial divergences on the order of 50 to 100% have been explained by program errors. The remaining divergences, however, seem to be more closely related to the methods utilized, in particular, for the calculation of solar gain (3).

As the comparison with this fictitious building was not totally satisfactory, a project entailing the detailed comparison with a real building was initiated (*Project IV*). The chosen building is located in Glasgow, and it had been instrumented during 1980 so that the first simulation could be done in 1981. It is a relatively complex commercial building with air conditioning and it is anticipated that about a dozen programs will be used for its simulation. Switzerland and the United States will both use the program DOE-II for the task.

In addition to the program DOE-II, there exists a number of other computer programs in different countries. These programs can be generally classified in two categories: complex programs that are most appropriately suited for complicated buildings and which require a substantial amount of time for both computation and the preparation of initial data, and simplified programs which are most appropriately suited for residential houses.

Project III-A of the IEA has provided the opportunity to make a comparison between two large programs, including DOE-II, two simplified programs calculating the thermal load on an hourly basis, and seven simplified programs based upon more or less static methods. The programs were given the task of simulating a fictitious building of 64 apartments on eight floors (the "Technikern" building) (5) and an instrumented, electrically heated house of 110 m^2 situated at Vetlanda in Sweden (6). For the house, the electricity consumption was measured with and without inhabitants and meteorological data was taken for more than six months. Studies in which different parameters were varied were also made: modification of the windows, decrease in the amount of insulation, night temperature set back, installation of an insulating carpet, increase in the ventilation. Switzerland participated in this project with the program JAENV from EMPA (7) and DOE-II. The final report will soon be published. The first results show differences of more than 30% between certain programs for "Technikern" and of the order of 15 to 20% with regard to measurements for the Vetlanda house (5).

Aside from the project of the IEA, EMPA has recently published the results of a computer program (7) concerned with the energy consumption of typical Swiss buildings. This program called JAENV, is based on daily climatic data and is simpler than the DOE-I and II programs. The conclusions of this work are interesting: the k-value and the inside temperature are really the determining parameters whereas the influence of the size of the window and the thermal inertia are not particularly significant factors. In addition, the energy index of apartment buildings should be half the index for small houses. It is necessary to stress, however, that this program has not been experimentally validated, and with respect to the relationship between the energy consumptions of large buildings and houses, the results of the statistical studies on energy indices contradict this prediction. The curves obtained by JAENV are reproduced in figure IV of Appendix II.

One other interesting conclusion of this work is that for buildings designed within the framework of classical architectural principles, it is possible to reduce the energy consumption for heating by a factor of two by increasing the insulation in the walls and decreasing the rate of air renewal, both in certainly acceptable proportions:

exterior walls	k	: 0.9 → 0.3	W/m^2K
windows	k	: 3.1 → 2.1	W/m^2K
inside walls	k	: 1.5 → 0.6	W/m^2K
ventilation	$\bar{n}$	: 0.72 → 0.45	h^{-1}

The other programs in Switzerland that should be mentioned are TRNSYS of EPFL (8), IGLOU from Motor-Colombus (9) and, for the study of passive solar houses, the program DEROB of the University of Texas which is also available at EMPA (4).

Most of the research on simplified programs, for example those applicable for microprocessor use, has been done outside of Switzerland (10). It should be mentioned that Berkeley (11) has developed an energy audit program for a house which can be run on a portable microprocessor. The audit gives an ordering of energy saving measures according to their economic attractiveness. Micro-computers can also be used to analyse low energy passive solar houses (12). This trend towards simplification, given that energy savings are a practical goal, will certainly have to develop just as the trend towards the more thorough understanding of fundamental building physics. The development of this knowledge is necessary because even if in principle the equations which describe the relevant phenomena are known, there remains the practical problem that even in the simplest of cases exact solutions are very difficult to obtain. The approximations of classical calculation methods are generally only valid for the relative comparison of simple variations of the same building. They can give no guarantee as to the absolute value of the results and can be hardly relied upon to yield useful information about structures that contain elements of non-traditional architecture: these include increased insulation, reduced infiltrations, solar contribution, etc.

Various theoretical research, especially in the United States, has been undertaken in order to develop computer programs which would be very reliable and more precise than the classical models. Let us mention two problems that have been recently studied:

The first example is that of <u>heat exchange by natural convection</u>. A recently published disertation on this subject (13) shows that the convective exchanges with the surfaces of a heated enclosure are strongly dependent on the distribution of the surface temperature. The use of an average surface temperature can cause errors on the order of 100%. This type of effect is particularly important in passive solar constructions where the surface is heated by the sun.

Another category of problems concerns the correct calculation of the solar contribution to buildings. This problem partially explains the observed divergences among the predictions of different computer programs studied in *Project I* of the IEA. In 1978 a disertation was written on analytical models of passive solar houses (14). This has enabled the development of the simplified program for a micro-computer that was previously mentioned (12).

2) Instrumentation

a) generalities

The detailed comparison of calculated predictions with real buildings necessitates their very complete instrumentation. This means that the building is equipped with apparatus that measures climatological date (outside temperature, insolation, wind speed), the inside temperature, the duration in which windows were open, the energy contribution recorded by the metering of the amount of heat, gas or electricity, etc. In Switzerland, the principal projects are La Sallaz (EPFL) (15), Maugwil (EMPA) (16) and the retrofitted buildings on Limmatstrasse (EMPA) (17) in Zurich. In addition there exist a large number of projects that have been undertaken in a more or less independent fashion, and a perusal of these projects immediately indicates that the different measures are, in fact, difficult to compare. Thus the establishment of standards in this area is essential. *Project III-B* of the IEA concerns precisely the writing of an experimental design handbook for instruments and measurement techniques. The Swiss contribution to this project is conducted by the EPFL (13).

b) instrumented buildings

In Switzerland there are the two buildings being studied within the framework of *Project III-C* of the IEA (Maugwil and La Sallaz) and the project financed by the city of Zurich and the NEFF on Limmatstrasse.

The building at La Sallaz: This project is being conducted by the EPFL and its main goals are a detailed study of the major components of the buildings thermal balance, a comparison with theoretical consumption calculations and the influence of inhabitant behavior. The building, constructed in 1975, contains 24 apartments and was instrumented in 1980 and it is expected that a controlled retrofit is forthcoming (15).

The buildings on Limmatstrasse: Both PLENAR and EMPA are responsible for this project. The purpose of this pilot experiment is to investigate and compare the possibilities of thermal improvement in urban dwellings. There are 25 houses of nine apartments each, constructed between 1908 and 1909, which have been retrofitted according to diverse schemes [17]. Before the retrofit (1976/1977) climatic data was taken (outside temperature, insolation, wind speed, etc.), inside temperatures and the energy inputs (heat, gas, solar, etc.). In the retrofit, supplementary insulation of outer walls was applied inside ($k = 0.5$ to $0.4\ W/m^2K$) and triple gazed windows were installed. Among the systems tested were heat pumps, solar collectors, and microprocessor controlled heating systems.

The house at Maugwil: EMPA is leading this task (16), and it involves a non-inhabited house in which data has been accumulated since the summer of 1979 and this is projected to continue until sometime in 1981. Some very detailed measurements have been made especially concerning air infiltration. The results indicate that even though the house has been carefully constructed, only 20% of the infiltration occurs at known openings (windows, doors, etc.) and 80% at unknown openings (123). The total collected data will enable a detailed comparison with the simulations of the program DOE-II under the auspisces of the IEA's *Project III-A* and validate realistic methods by which air infiltration can be calculated. Finally, the energy consumption data of this non-inhabited house will be compared with that of very similar houses in the same neighborhood in order to deduce information about inhabitant behavior.

Other houses that have been instrumented in Switzerland are at Begnins (18), Payerne (19) and Zug (20).

Outside of Switzerland there are of course many instrumented houses. For instance, the IEA projects at Glasgow and Vetlanda are instrumented in order to provide data for the comparison of calculation programs (16).

3) Air renewal

The energy consumption for heating depends to a great extent on the air renewal rate. In a standard building this consumption represents 20-30% of the total. In a low energy consumption building, however, and in proportion to the increase in insulation, the fraction of heating energy that is used to re-eat fresh air increases rapidly to over 50%. In order to continue the reduction of energy consumption for heating, it is thus necessary to thoroughly study all the aspects of fundamental problems related to the air change rate.

a) instrumentation

It is first necessary to determine with precision the air change rate in a given building as well as the instrumentation and the methods amenable to a normalization which allows for a comparison of data between various countries. The IEA, within the framework of its *Project V*, is therefore preparing a handbook on air infiltrations, their reduction and measurement methods and instruments. The Swiss contribution to this handbook is being written under a mandate from the Federal Office of Energy and the measurement techniques are being studied at EMPA (21, 123).

b) air quality

A very important and related problem is the air quality. Air renewal is necessary because of chemical, and possibly radioactive pollutants and the simple need to eliminate odors. Numerous works have already been completed outside of Switzerland in this subject (22). There is currently a project in Switzerland at the ETHZ (23).

An important result emerging from these experiments is that the air renewal rate cannot be easily lowered to less than 0.5 air changes per hour. It is for this reason that most of the recent pilot-houses with very low energy consumption use air-to-air heat exchangers. This ensures an air renewal

compatible with the requirements of maintaining an acceptable air quality while recovering the maximum of the heat from the stale air to be expelled from the dwelling (24).

Project IX of the IEA, which has been proposed by Germany, is stated to determine the minimum acceptable air change rate in dwellings. Switzerland also participates in this project.

c) Air Infiltration Center

In order to collect information concerning problems of air infiltration (non controlled air renewal), *Project V* of the IEA has established an Air Infiltration Center in England (25). This center publishes a periodical and technical publications which can be obtained at EMPA. The coordination of this project is EMPA's responsibility.

d) inhabitant behavior

Another question is the behavior of the inhabitants who, independently of scientific facts, have certain habits which it would be advisable to know. The projects at Maugwil and La Sallaz are partially committed to the study of this behavior.

In low energy buildings ventilation habits can modify in a noticeable fashion the average air change rate, and can thus considerably increase the consumption of energy. In a German study on 2000 apartments (26), it was observed for example, that in 40% of the cases, the dining room window was open for approximately 15 minutes one or two times during the course of a day. On the other hand, in nearly 50% of the cases the bedroom window could be easily left open for more than an hour per day.

In order to thoroughly study these questions, Switzerland, at the initiative of EMPA (27), has proposed *Project VIII* to the IEA in which the goal would be to precisely analyze the behavior of the inhabitants with respect to ventilation. Several countries have already announced their eventual participation in that project and it is possible that the final contents of this proposal will be accepted in 1981.

e) research trends

In the areas of air quality and renewal the following trends can be noticed (28):

- construction of buildings with reduced uncontrolled air infiltrations;
- mechanical ventilation with flow control as a function of needs and heat recovery;
- air quality monitoring;
- accounting for the number of occupants;
- improvement of ventilation for the elimination of pollutants and tobacco smoke;
- creation of zones reserved for smokers;
- development of new air cleaning apparatus;
- control and elimination of pollution sources;
- improvement of air distribution systems.

4) Indoor climate and thermal comfort

From the physiological point of view, building occupants are subjected to an environment characterized by a certain level of light, noise, and to what is termed as indoor climate. This environment and indoor climate should satisfy certain requirements dictated by hygene, comfort, and if relevant, the nature of occupant activity (work). The indoor climate is characterized by the two principal elements of air quality (discussed in the preceding paragraph) and thermal comfort.

Six factors determine thermal comfort, which can be defined as the manner in which the occupants sense the characteristics of the surrounding air (29):

1. the occupants activity level;
2. the occupants clothing level;
3. the air temperature;
4. the relative air velocity;
5. the thermal radiation;
6. the humidity.

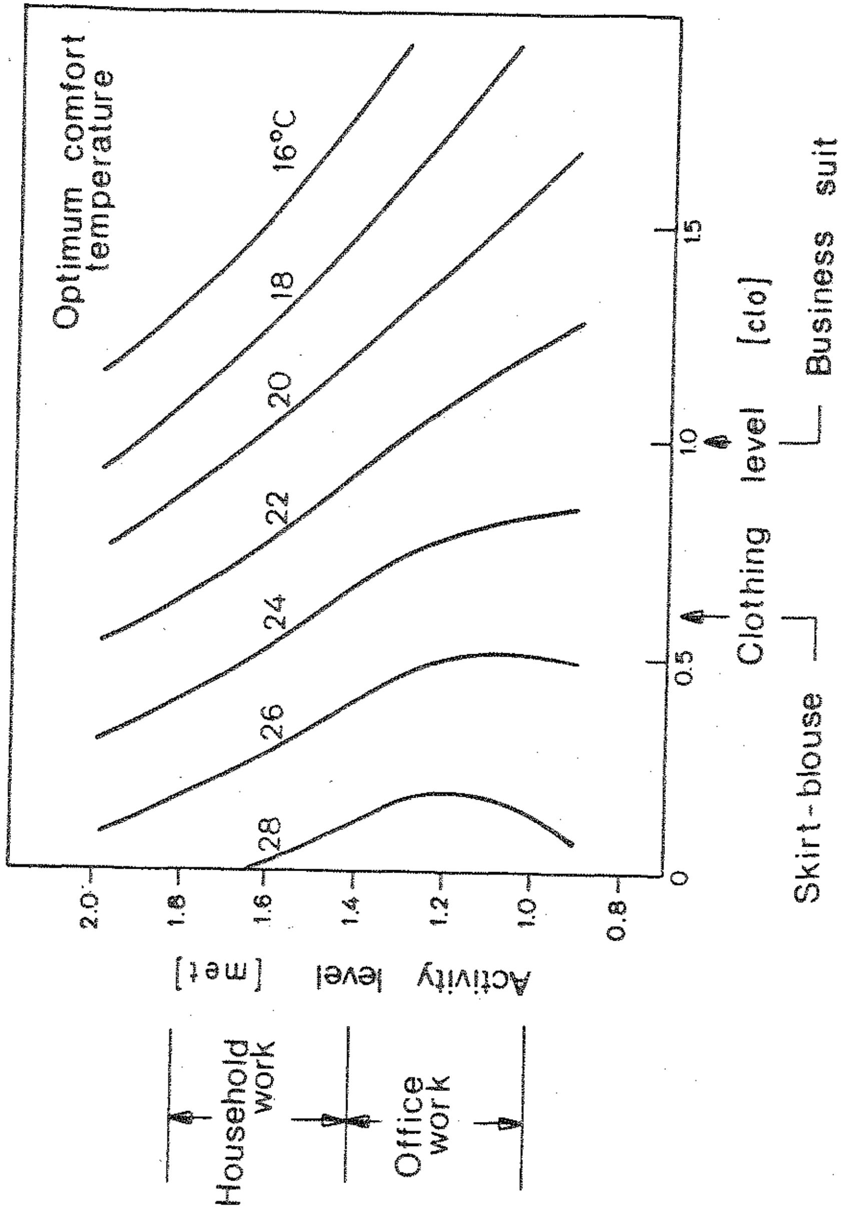
The two "people"-factors, 1. and 2., are conventionally described by units corresponding to a standard metabolic activity (1 "met" = 60 W/m^2: the metabolic activity of a person sitting) and to a standard clothing (1 "clo" = 0.155 m^2K/W: the level of clothing of a man wearing typical business dress, which corresponds to a coefficient k of 6.5 W/m^2K).

Within the past few years there has been some important research attempting to scientifically determine the requirements of sentient comfort as a function of the six aforementioned factors. The results of a Danish study (30) indicated that the "optimum" temperature for a clothing level of 1 clo and an activity of 1.2 met (seated office work) was 22°C. Under the same conditions other experiments showed similar results, but sometimes indicating this temperature to be lower and on the order of 21°C (31). Several remarkable conclusions emerged from these studies:

- For a given set of activity and clothing conditions, the diverse external factors of comfort (temperature, humidity, relative air velocity, etc.) are practically independent of the sex and age of the people as well as the other parameters of the environment (noise, colors, etc).

- The human organism is extraordinarily sensitive to small variations in these comfort factors. For example, drafts greater than 15 cm/s, a temperature difference of 3°C between the head and the feet,...can engender feelings of discomfort.

- An additional, though even somewhat slight, activity or clothing level can easily decrease the optimum comfort temperature by several degrees. Figure I, for example, indicates that for office activity (1.2 met), the addition of a wool sweater (0.3 clo) lowers the optimum comfort temperature by about 2°C (29).



Optimum comfort temperature as a function of activity and clothing levels

Figure 1

An important consideration with regard to these studies is that the efforts taken, from an energy conservation perspective, should guarantee not only a reduced energy consumption but also an increase in comfort. In this sense, however, it is important to distinguish thermal comfort, as it is defined in this paragraph, from "social comfort" (which corresponds for example to the habit of heating all the rooms of a house for the whole day) and "operating comfort" (which corresponds for example to the habit of ignoring the possibilities of manually controling the functioning of the heating system).

It is well known that a 1°C decrease in the inside temperature yields a reduction in energy consumption on the order of 5% (7). Similarly to the reduction of the air exchange rate, this decrease has direct consequences on the indoor climate and thermal comfort. For these reasons, the research in this domain is currently developing in the following directions (28):

- localized heating and cooling which ensures the comfort of the individual at the specific place of occupancy;
- decrease in the velocity of drafts;
- implementation of temperature profiles as a function of hours in the day;
- sophisticated temperature controls;
- individual temperature controls;
- vertical temperature control;
- development of new work clothes;
- development of standards based on human needs, ensuring a constant comfort rather than a constant temperature.

5) Construction standards

In Switzerland, construction standards are developed by the Society of Engineers and Architechts (SIA) (32). These standards are then eventually introduced into cantonal legislations. Because the life time of a building is relatively long, it is appropriate that the construction standards as well as their subsequent modifications should be thoroughly studied. Since 1973 numerous countries have adopted new construction standards and, in 1977, the SIA introduced standard 180/1 (revised in 1980) concerning thermal insulation of buildings, and in 1980 the standard 180/3 concerning the calculation of a building's annual thermal energy load. The sizing of heating plants is prescribed in standard 380 of 1975 (revised in 1980).

There are two research projects regarding these standards currently in progress. One project, conducted by EMPA, is the development of an apparatus to measure the coefficient k of existing walls (33). Such an apparatus will allow for the verification of the correct application of the standards and for the measurement of the characteristics of old walls with a view towards their thermal retrofit. The other project, under the auspisces of the NEFF, is a study by the SIA on the revision of standard 380 (34).

The 180 series of the SIA standards prescribes a procedure which is referred to as the "admissible average k", or the $\bar{k}$ method. Another method, applied in France, for instance (35), uses the coefficient "G". With the definitions given in Appendix II:

$$G = \frac{A}{V}\bar{k} + 0.34\,\bar{n}$$

The parameter G, which accounts for transmission losses ($\bar{k}$) and air renewal losses ($\bar{n}$), characterizes the thermal qualities of the building because it is approximately proportional to the energy consumption for heating. The method using the coefficient G consists of assigning it a maximum value as a function of different criteria such as the geographical location and the building type.

The method of the average k coefficient, used in Switzerland and Germany in particular, consists in determining an admissible maximum value for the parameter $\bar{k}$ as a function of the building form factor A/V, the altitude at which the building is located, and the indoor temperature of the main rooms.

In addition to the maximum $\bar{k}$ value, the standards prescribe the maximum values for the respective coefficients k for each of the building components as well as for ventilation and air infiltration rates.

The justification for the principle of the methods "admissible average k" or "coefficient G", is the idea that they yield an energy consumption per unit of heated surface area which would be equal for all buildings of the same shape, geographical location, and purpose. These methods thus essentially tend toward standardizing, but not minimizing, the energy index.

Several comments can be made with regard to these methods. In particular, a detailed analysis of the SIA standards shows that the insulation of the large apartment buildings on the Swiss plateau can still be improved (36).

From the perspective of energy conservation, at least in principle, other methods of normalization are possible. More specifically, there are methods which minimize the building's energy consumption in an absolute sense by imposing conditions of uniform insulation, via more severe maximum k values for each of the respective building components. The following table compares the maximum admissible coefficients k for Switzerland, Denmark, and Norway. For Switzerland, the model regulations for cantonal prescriptions on thermal insulation proposed by the Confederation prescribe more severe maximum k-values for certain exceptional cases (37).

maximum admissible k coefficients

	Switzerland (1977)	Denmark (1979)		Norway (proposed)
Outside walls	0.6	0.25	0.35	0.4
Windows	3.3	2.7	2.0	2.6
Roofs	0.5	0.2		0.2
Floor over cellar	0.8	0.3		0.3
Floor over ground	0.8	0.4		0.3

Another conception, related to the development of calculation programs, leans toward the optimization of a larger number of parameters (particularly of the solar contribution), which not only allows for a minimization of the building's initial cost, but also of the total, integrated life cycle costs. In the United States the Department of Energy is in the process of specifying a new national standard which, if accepted, will be one of the most demanding in the world, and which would precisely bring to the forefront these types of new ideas (38). The new standard, called BEPS (Building Energy Performance Standard), specifies minimum performances: each new building should be constructed in such a way that its energy index would be less than that of an index based upon a standard which depends upon, among other factors, the climate. The contractor is free to choose the solution of his preference provided that it appropriately respects the standard. This project is currently the object of numerous criticisms, especially from the builders's associations and the electrical utilities (39).

Concerning air infiltrations, the current Swiss standards prescribe minimum levels of tightness for windows and frames. In Sweden, a different approach has been adopted which imposes a maximum admissible infiltration rate for the entire building. For a pressure difference of 50 Pascal, the maximum infiltration rate is thus three air changes per hour for houses, and one air change per hour for buildings of more than three floors.

In general, the numerous theoretical and experimental results that have been documented within the past few years indicate that those standards recently accepted or currently under development, in many countries, are still very modest with respect to the possibilities and the economical profitability of energy conservation in buildings (40).

6) Thermal retrofit of existing buildings

According to an estimate made in 1976, the construction of new buildings between 1975 and the year 2000 will only replace 25% of the total volume of Swiss buildings (41). This figure underlines the primary importance of thermal retrofit in existing building and even suggests that the available energy savings for that time span has probably more of a potential in thermal retrofit than in the construction of new buildings.

Another characteristic of the Swiss building stock is the relative importance of apartment buildings.

As a function of respective heated surface areas, the building-type distribution in 1975 was the following (42):

Houses with 1 apartment	28%
Houses with 2 apartments	10%
Multi-apartment buildings	38%
Diverse buildings with apartments	24%

The English-speaking and Nordic countries are currently the most active in the field of energy conservation in buildings. The majority of the research in these countries concerns individual houses and administrative or commercial buildings. In addition, in some of these countries, especially the United States, the quality of existing buildings is mediocre in comparison to the typical Swiss constructions. It is thus essential to account for these differences when analyzing these studies, especially when they concern thermal retrofit.

a) methodology and politics of thermal comfort

For each particular thermal retrofit situation one is confronted with groups of measures from which it is necessary to choose those that are technically the most proven and economically the most attractive. On the micro-economic level of a given building, a simple cost-benefit analysis suffices to determine this optimum. On the macro-economic level of a large building stock, particularly at the regional or national level, it is necessary to also confront the socio-political problems posed by thermal retrofit and to study the different measures which will encourage this type of renovation on a large scale. The research in this area should lead to the elaboration of concepts and detailed strategies concerning the technique of thermal retrofit itself as well as the global approach to the problem at the level of a region or a country.

Within the framework of sector I of the national program "Research and Development in the Energy Domain", the FNRS finances three projects touching upon these questions:

- "Effects of energy policy instruments" (36). This research investigates the overall problem of energy conservation in the built environment. It analyses the probable impact of various proposed or enacted legislation or technico-economic measures.

- "Strategies for energy savings" (42). This research examines in detail 27 cases of buildings amenable to thermal retrofit with the goal of determining the socio-economic mechanisms which encourage or inhibit their renovation. Among the apparent problems, not to mention all of them, are economic attractiveness, contractor motivations, possible conflicts between renters and owners, etc.

- "Energy savings in existing buildings" (43). This study considered in detail the possibilities of thermal improvement in 19 administrative buildings corresponding to 3820 work places. This research indicates that when the potential technically feasible energy savings for these buildings is 52%, the economic attractiveness is constrained to 29% savings.

All of these studies clearly indicate the need of a methodical approach to the problem of retrofitting. This generally includes four or five phases:

I. Rough analysis of the buildings
II. Fine analysis of the buildings
III. Selection of improvement measures
IV. The actual retrofit
V. Verification of results

Within the framework of its "Impulse Program", the Federal Office of conjectural questions organized refresher courses on building thermal retrofit. These courses teach a methodology based precisely upon the above mentioned approach and a handbook has also been published (44).

Project VII of the IEA, proposed by Sweden, is centered about the socio-political problems posed by energy conservation planning in urban communities. This project will particularly study those buildings for which there exist relationships of the type "owner/tenant": rented buildings, multi-apartment blocks, small commercial buildings, public buildings, etc. Another part will be for the study of relations of the type "government/community": this project will examine the conditions which will help to strengthen coordination with non-governmental actors: energy retailers, large consumers, professional and consumers associations,...

b) energy audit

The above methodological considerations underline the importance of the initial phase of the process of thermal retrofit. This is the energy audit which is the precise evaluation of a building's thermal characteristics, the possible improvements, and the selection of optimum measures (46). Some American researchers consider that this type of work should correspond to a new profession: the "house doctor". They claim in effect that the building constructors, the heating installers or the makers of insulating materials are not inevitably the best suited for this type of a complete evaluation (47). Sweden proposed that a new IEA project should be dedicated to housing energy audit.

In order to facilitate the energy audit, there is the previously discussed development of simplified computer programs capable of assisting the auditors. Such an audit can be accomplished by two people working for half a day; it encompasses measurements of air infiltration losses, the boiler efficiency, the thermal resistance of the walls and the history of the houses's energy consumption. It concludes with an optimal choice of remedies (11).

A Swiss firm offers a micro-processor based system of retrofit optimization. This system functions uniquely on the basis of construction plans and would in no case replace the visit "in situ" of an auditor (48).

The IEA organized a seminar on energy auditing in April 1981 in which Switzerland presented several contributions (181).

c) retrofit techniques

The technical aspects of thermal retrofit pose a certain number of problems of which the solutions are only partially related to the development of new construction techniques for new buildings of low energy consumption. Because the number of interesting and large scale retrofits in the world today is still limited, a considerable effort is underway to analyse and generalize the results obtained in the pilot retrofits. For this task the IEA is called upon to play an important role, and its *Project III-C* consists precisely of encouraging such exchanges. It is through this project that, in Switzerland, the instrumented buildings at Maugwil and La Sallaz will eventually become the object of pilot-retrofits. Similarly, the results of Limmatstrasse and of the "Solar House" in Zug will become more valuable in this manner.

Also within the framework of this IEA project, a seminar on the thermal retrofit of windows was organized in 1980. Denmark prepared a contribution on supplementary insulation in walls and the United States for that in roofs. Finally, Sweden is studying heat recovery in ventillation systems.

We have already mentioned the importance for Switzerland of thermal retrofitting of large apartment buildings. It is interesting to realize that unfortunately there exist only a very few retrofit cases of such buildings for which complete data is available.

In paragraph 8 below we will examine a certain number of pilot retrofits which will provide us with the occasion to illustrate certain technical problems as well as the most important ones of thermal improvement in existing buildings.

PILOT STUDIES

As it was stated in the introduction, a pilot building should provide a certain amount of data such as specific consumption (before and after the retrofit when required), general characteristics of the building, the number of degree-days and the additional costs. In fact, it is unfortunately often very difficult to obtain this information.

For this reason we will restrict ourselves in the two following paragraphs to the presentation of some chosen examples of constructions and pilot retrofits for which the figures are available. In making this selection we have restricted ourselves in general to studies with which university establishments or governmental agencies have been associated and which have led to publications. From among these studies, we have retained those that we considered the most interesting, either from the viewpoint of their performance, or their importance for the research in the area of building energy conservation.

7) Low energy pilot-buildings

There exist certainly in the world today thousands of constructions in which the energy consumption is significantly less than that of conventional buildings constructed in their proximity. From among the low energy constructions it is often difficult to separate in practice those which qualify as "solar constructions". The present study does not treat solar energy in the strict sense, and we will only consider "highly insulated constructions", even though, in general, a step toward the optimum use of the passive solar contribution was of course made.

In table I we have classified, as a function of their energy index, a selection of particularly interesting pilot-house. It can be claimed that it is possible to realize habitable houses in which the energy consumption for heating normalized to the Swiss average (3654 degree-days with respect to $20^{o}C$) is in the neighborhood of 100 MJ/m^2 year. This energy index is lower than half

TABLE I

MEASURED HEATING PERFORMANCES OF SOME HIGHLY INSULATED PILOT - HOUSES

	References	Symbol	Number	Heating plant type	Insulation (W/m^2K) walls	ceiling	floor	Air to air exchanger	Local degree-days	Energy Index (MJ/m^2) local	normalized
Canada		CA1	1	Electricity	0.14	0.09	0.18	X	6463	27	15
USA		US1	1	Electricity	0.17	0.14	0.26		3860	87	82
USA		US2	1	Gas	0.16				4201	103	90
Canada		CA2	5	Electricity	0.14	0.09	0.19	X	6157	168	100
USA		US3	1	Electricity	0.16	0.15	0.11		5060	156	113
Scotland		GB1	24	Electricity	0.33	0.22	0.22		3638	83	83/165
Canada		CA3	2	Gas	0.14	0.09	0.19	X	6157	210	125
Fed.Rep.Ger		AL1	1	Electricity	0.17	0.23	0.3	X	3400	124	133
Denmark		DA1	1	Electricity	0.19	0.15	0.14	X	3000	164	200
Sweden		SU1	5	Electricity	0.28	0.16	0.29		4583	270	215
England		GB2	20	Electricity	0.31	0.31	0.41		3915	135	126/285

of those measured in houses constructed according to the current swedish standards (SU1 in the table). The numbers in this table are plotted on figure II in chapter V which also shows the results of different consumption statistics and the predictions corresponding to the new standards proposed for the United States.

We will now present a review of several examples of pilot-projects.

a) England

- Nearly 600 prefabricated houses, insulated by 10 to 15 cm of fiberglass, have been constructed in the Aberdeen region of Scotland. These houses are heated electrically and their performances have been the subject of several publications (49). In these houses the electric consumption for heating only represents 25 to 35% of the total consumption. The air change rate is around 0.2 to 0.3 air changes per hour and the inside temperature is maintened at different values depending on the kind of room (see chapter III § 1). Twenty-four of these houses have been studied in particular detail: separate measurements of the energy consumption for heating, hot water and other household requirements, observations of ventilating habits, etc. The energy indices measured in this study are included in tables I and IV. Individual variations of more than a factor of two are observed for these indices and can be correlated with the behavior of the inhabitants.

- The school of architecture at the University of Newcastle has been given the task of building a group of 38 low energy consumption houses at a price no greater than 10% more than cost of traditional construction (50). The analysis of the consumption for the first year (1977 / 1978) for 20 houses has shown that the measured energy index for heating of 135 MJ/m^2 is in fact 30% higher than the calculated index. A detailed examination of one of these houses seems to indicate that this excess consumption is due to a quality of insulation that is worse than expected.

NB: One of the important characteristics of both series of English houses described above is that the inside temperatures are different, depending upon the room, and that generally only the living room is heated to 20°C. In table I we have thus normalized the energy index of the group of Scottish houses, (GB1, where the mean inside temperature was 15.6°C, giving an energy index of 83 MJ/m^2), to Switzerland, where the whole house is maintained at 20°C, giving 165 MJ/m^2. For the houses in Newcastle GB2, in which the average inside temperature is 14,5°C, the normalized indices are 126 and 285 MJ/m^2 respectively. In calculating these indices we have considered that 50% of the energy used for hot water and general domestic purposes effectively contributes to heating.

b) Canada

- The University of Saskatchewan has designed a 188 m^2 superinsulated house with an energy index measured in 1978/79 of only 15 MJ/m^2. This experimental house (51) is not occupied in the usual sense although the number of visitors and the energy contribution (5'500 kWh/year) of the measurement apparatus that it contains practically simulate a normal occupation. The passive solar contribution is evidently optimized and it is claimed that the active solar system which is forseen will provide the hot water necessary for both heating and domestic needs. This house is equipped with both air and water heat recovery systems. The ventilation rate is 0.6 air changes per hour and the total building envelope is sealed by a vapor barrier. Another particularity of this house is that it utilises insulating shutters which reduce the coefficient k of the windows to a value of 0.35 W/m^{2}K during the night (CA1 in table I).

- The experience acquired in the construction of the above mentioned house has led to the building of approximately 50 superinsulated houses in Saskatoon. In this region, where the number of degree-days is approximately 6160°C relative to 20°C, the energy index for heating is 670 MJ/m^2 year for conventional houses with electrical heating. The energy index measurement for 13 of these houses varies, with the exception of two of them, between 121 and 240 MJ/m^2, and the average of the 13 is 218 MJ/m^2 (52). The corresponding energy index for heating in Switzerland would be 130 MJ/m^2 (CA2, CA3. Also see chapter II § 5).

c) Denmark

- A number of low energy houses have been recently constructed in Denmark (53) and the house DA1 of table I is one of the first published results (54).

- The Ministry of Commerce mandated the Technical University of Denmark to design and construct six 120 m^2 low energy houses in which the total energy consumption for heat, hot water, and ventilation was not allowed to be greater than 150 MJ/m^2 (53,55). These houses are unique in both their details and their heating systems. Good performances are obtained because of a large amount of insulation (20 to 30 cm in walls and floors, 40 cm in ceilings), a reduction of uncontrolled infiltrations to below 0.1 air changes per hour and the use of a heat exchanger for ventilation. Detailed tests on these houses have been conducted since 1979 and the sale of these houses was anticipated for the end of 1980. The price of these houses should be from 20 to 50% higher than those of comparable construction for a total amounting to between 201'000 and 300'000 francs.

- Two small apartment blocks (34 apartments) have been constructed for the city of Skire in the Jutland region (53). According to the predictions the energy consumption should be less than 270 MJ/m^2. The central energy plant provides hot water for the low temperature heating system and domestic usages as well as preheated fresh air for ventilation from a heat recovery system. The water is heated by heat pumps and solar collectors.

d) United States

- Several low energy houses such as US1 and US2 (56) have been constructed in the United States. They are characterized by insulation similar to that in the Canadian houses and by very reduced infiltrations, but generally without using air-to-air heat exchangers. The good performances of these houses without heat recovery from expelled air are probably due to a warmer climate.

- About a hundred houses of the US3-type have been constructed in the New York area (57). These houses have a heated surface area of 215 m^2, are wood constructions and are built on a 50 ton sand bed whose insulation from the earth allows the storage of the eventually excessive solar heat that is captured passively by the building. This heat is used to stabilize the inside temperature.

- The US3 houses that we have described are not in the strict sense the type of passive solar house that presently exists by the thousands in the United States. These passive solar houses are mostly situated in the more temperate regions and consume no more than 20 to 50 MJ/m^2 per year in the form of auxiliary heating energy on the coldest days. A compilation of passive solar pilot-houses has been recently published by the Los Alamos National Laboratory (58).

e) Federal Republic of Germany

The Philips research laboratory at Aachen constructed a highly insulated experimental house in 1974 in order to test some diverse techniques such as heat recovery from air and from water, heat pumps, solar collectors, etc. The performances measured in 1975/1976 for this house are shown in AL1 of table I (59).

f) Sweden

- New construction standards were introduced in Sweden in 1975 (SBN-75). The uniqueness of these standards is that they not only impose very strict conditions for insulation, but also for air renewal rates. In order to verify the effect on energy conservation resulting from the new standards, the Royal Institute of Technology participated in the construction and performance measurements of 5 houses with heated surface areas of 140 m^2 each near Stockholm. Very thorough measurements have been made for the 78/79 and 79/80 heating seasons and have just been published (60). The coefficients k of walls, roofs, floors and windows are respectively 0.28, 0.16, 0.29 and 1.90 W/m^2K. The average k coefficient is 0.28 W/m^2K. The average air change rate measured for the five houses for the two years is 0.46 air changes per hour. The total energy index measured under the same conditions is 425 MJ/m^2 (for the heating index see SU1 in table I). All of these houses were normally occupied during the measurements and it was possible to make detailed studies of various parameters such as the humidity level and CO_2 concentration, thermal comfort, etc.

- Another group of 41 houses was constructed at Täby, near Stockholm, according to the new standards with 15 cm of insulation in the outside walls and 25 cm in the roof (61). Of these houses, 26 were instrumented in 1977 and equipped with seven different heating systems (see chapter III § 3a)).

- The pilot-house at Vetlanda is used as a reference house by the IEA for its projects. The house is an 113 m^2, wood frame-type set on a concrete base. The insulation consists of 19 cm of fiber glass in the walls, 30 cm in the roof and 12 cm in the floor. The uncontrolled infiltration rate was measured as being between 0.03 and 0.08 air changes per hour. The energy index measured during the winter of 76/77 was 328 MJ/m^2 while the house was unoccupied. Within the framework of *Project III-A* of the IEA this energy consumption was compared with the predictions of 12 computer programs. The preliminary report on this comparison shows that the theoretical calculations have a mean deviation of 15% from the measured value (5,6).

- The current construction trend of low energy consumption houses in Sweden moves in the direction of very substantial amounts of insulation. A group of 32 houses as well as a tenant building with 32 apartments are under construction and their thermal parameters are the following: wall and roof insulation, 0.18 and 0.10 W/m^2K respectively, small windows, uncontrolled infiltration rates of 0.1 air changes per hour and mechanical ventilation with heat recovery. The anticipated heating energy index is between 110 and 130 MJ/m^2 year (176).

g) Switzerland

There exists in Switzerland, as in other countries, many houses and buildings with relatively low energy consumption. These structures were generally motivated by the private initiatives of individuals or the efforts of public enterprises such as the Confederation or certain cantons. The Swiss Movement for Energy Savings (SAGES) undertook a compilation and expects to publish a selection of particularly interesting low energy consuming Swiss buildings. With the exception of a few projects utilizing either active or passive solar systems, there do not presently exist pilot-studies comparable in scope to those we have described for other countries and which correspond to the criteria defined in the introduction of this section.

Nevertheless, without the pretense of being complete, several examples can be cited:

- In the area of active and passive solar: houses at Payerne (19), at Begnins (18) and at Minusio in Tessin (62).

- In the area of highly insulated houses: three pilot-houses at Hinteregg near Zurich equipped with a collective heat pump and for which the measured energy index for heating and hot water is 170 MJ/m^2 (63). Two houses of 5 apartments each, equally well insulated and heated by a heat pump have just been completed at Gossau (64). From among the houses heated with oil, one of the best measured results that we were able to find seems to be that of a house retrofitted at Rudolfstetten in which the energy index for heating is 305 MJ/m^2 (65). There exist equally many examples of electrically heated houses in which the occupants use the flexibility of temperature control offered by this heating system and which attain energy indices for heating as low as 220 MJ/m^2 (66).

- In the non residential domain: we mention first the efforts of the Confederation which has succeeded for example in obtaining substantial energy savings in the construction of new administrative buildings at Bern (67) and at the EPFL at Lausanne. In the case of the EPFL, measurements of long duration concerning the energy used for the heating and ventilation are in progress (68). Another example is the Cantonal chemistry laboratory in Zurich in which the energy consumption only represents 50% of a similar building's consumption but of classical design (69).

8) Pilot-retrofits

A few cases of thermal retrofits that were completed several years ago, especially in the United States, have attained spectacular results and received considerable publicity. Many retrofits completed since then, however, have not always met with the anticipated success. It becomes, thus, more and more evident that thermal retrofitting necessitates a previously thorough thermal audit and considerable care with respect to the quality of the work. For these reasons the realization of a sufficient number of pilot-retrofits is indispensable.

a) England

- The Electricity Council Research Center at Capenhurst has at its disposal a set of six identical, neighboring houses which are similar to and representative of the existing English building stock. The six houses are all thermally insulated to different levels such that their average coefficient k ranges between 0.69 and 1.28 W/m^2K. This situation allows for a large number of interesting experiments and studies have been made in particular for the comparison of simplified calculations with the measurements (70) and the influence of the insulation level on the solar contribution (71). There is currently a retrofit experiment in progress with the goal of improving the insulation in the house with an average coefficient k of 0.69 down to 0.47 W/m^2K (72). The first measurements have shown that, in fact, the average k achieved was only 0.61 W/m^2K. A detailed analysis indicated that this deviation was mainly due to the mediocre performance of walls insulated by means of injected foam, of residual thermal bridges and other secondary causes.

- The Building Research Establishment Scottish Laboratory undertook a retrofit experiment on 38 similar houses (73). Twenty houses have been kept as references (coefficients k of walls, ceilings and floors are respectively 1.7, 0.7 and 0.7 W/m^2K) and 18 others have been insulated (coefficients k of walls, ceilings and floors are 0.45, 0.3 and 0.7 W/m^2K). Theoretically, the decrease in energy consumption should have been 35%, but measurements have shown that the saving actually obtained was only on the order of 22%. This difference has been explained by the fact that the average temperature in the better insulated houses was in general higher than previous. For those houses in which the rooms are maintained at different temperatures, this phenomenon is due partially to the fact that a reinforcement of insulation in the outside shell necessarily increases the equilibrium temperature of the non-heated rooms.

b) Canada

- Canada undertook a vast program of thermal retrofitting involving a million houses. The average reduction of energy consumption achieved for these renovations was on the order of 17% (74).

- An essential problem to which Canada has paid particular attention is the oversizing of oil fired boilers. It is thus, with the support of the government, that different techniques of burner and boiler modification have been developed. It is now possible to obtain replacement parts and the necessary instructions in order to decrease the installed power of a large number of boiler and burner models. Using this technique it is easy, without replacing the boiler, to achieve savings on the order of 8 to 16% (177).

c) Denmark

- Several pilot-retrofits are in progress in Denmark. One of them concerns a block of 24 apartments, identical to four other neighboring blocks (75). A complete retrofit including, among others, supplementary insulation of the building shell, the installation of triple glazed windows and of thermostatic valves has lead to a decrease in the energy index from 714 to 428 MJ/m^2 for heating. This group of buildings is supplied by a central heating plant common to the 5 blocks, such that the decrease in consumption is essentially due to the improvement of the passive components of the block in question.

d) United States

- Three cases of pilot-retrofits involving individual houses have achieved a decrease in the energy consumption by more than a factor of two. These particularly thorough and carefully done retrofits have been made by the National Bureau of Standards (47), the University of Princeton (76) and the University of Oregon (77). In these three cases, the energy consumption after the retrofit was reduced to 41%, 33% and 42% respectively of the initial consumption.

- Numerous systematic retrofits have been undertaken in the United States, in particular with the collaboration of different electricity or gaz production and distribution companies which provide counseling services for thermal retrofitting and financial backing. A recent compilation, completed by the Lawrence Laboratory at Berkeley, has taken a large scale census of the most important results actually available from these retrofit programs (74):

Location	Number of houses	Consumption after / Consumption before
Portland	20	62 %
Tennessee	60'000	86 %
Oregon	4'300	77 %
Denver	30	92 %
Washington	520	91 %
Maryland	750	98 %
New York	60	86 %

e) France

An agreement concluded in April 1977 by the Ministery of the Environment and the Agency for Energy Savings set a goal to save, in the overall building stock, 15% of the energy consumption by 1985. At this point, 65'000 HLM dwellings have been improved in 1977 and 85'000 in 1978. Seven experimental programs have been initiated in 21'000 dwellings: outside insulation, inside insulation, regulation and programming, improvements of the active components, etc. (78).

f) Sweden

- Within the framework of the Swedish national program for energy savings it is possible to get loans and subsidies for, as an example, the supplementary thermal insulation of houses. A dissertation has been submitted at the Polytechnical School of Chalmers (79) and concerns 20 arbitrarily chosen buildings for which a supplementary thermal insulation has been effected with the aid of a loan or a subsidy. The study indicates that the savings are on the average the double (21-22%) of what one would expect from such insulation (about 12%). The study cites three factors as responsible for these unexpected savings:

(i) the subconscious desire to save energy; (ii) the higher temperature of the inside surface of outside walls; (iii) the decrease of uncontrolled infiltrations following the installation of the insulant.

- A survey covering 341 houses retrofitted between 1975 and 1978 allowed for the comparison between the results obtained with supplementary insulation and the theoretically anticipated savings. An average theoretical savings of 700 ± 100 liters of heating oil per year, has been found to correspond to an actual saving of 500 ± 150 liters of heating oil per year. In addition to this result, the most important conclusion of this survey is that the houses for which the greatest savings have been attained, are not those for which this was predicted, but those that had the worst energy indices before the retrofit.

g) Switzerland

- Several pilot-studies are directly or indirectly concerned with thermal retrofit. This is specifically the case of the projects on Limattstrasse and in La Sallaz which were mentioned in paragraph 2b) of this chapter, as well as the solar house in Zug (20). In the latter case, after a complete retrofit which lowered the average coefficient k to 0.44 W/m^2K, the energy consumption was reduced by a factor of two. This is a small tenant building comprised of six apartments on three floors and is located in the neighborhood of four other identical buildings. The renovated building will ultimately be equipped with a bivalent heating system consisting of a heat pump capable of accounting for 80% of the heating needs and an auxiliary oil burner accounting for the coldest days.

- A retrofit example that we have already mentioned concerns a 152 m^2 house at Rudolfstetten, heated by oil. The energy index has been lowered from 900 to 300 MJ/m^2 by different means but principally by a thermal insulation resulting in a coefficient k of 0.2 for the walls and 0.18 W/m^2K for the roof (65).

- In paragraph 6 of this chapter concerning retrofit, we have mentioned several theoretical studies and thermal improvement programs. For example, within the framework of a systematic thermal improvement effort of the Confederation building stock, a first series of measures undertaken in 31 buildings of the Federal Administration at Bern resulted in a 24% decrease in their oil consumption (80).

The city of Geneva offers another example in that the purchases of oil went from 7'400 tons in 1973 down to 4'500 tons in 1979, despite the fact that the buildings stock volume had increased in this time interval (81).

Conclusion

It can be said that there exists overwhelming scientific evidence, theoretical and practical, that a retrofit done in a very competent manner by highly skilled researchers leads to a remarkable reduction in energy consumption, and that this retrofit necessarily includes an improvement of the thermal insulation. The implications of this fact on a more practical level are much more subtle. A retrofit in which the various aspects have not been thoroughly considered can very well have disappointing effects. A thermal insulation, for example, done separately, can lead to an increase in energy consumption if the secondary effects (a change in the efficiency of the heating plant, a change in the temperature of cold rooms, etc.) are not anticipated and simultaneously corrected. The disparity between what can be achieved if everything is well done and that which is achieved in practice by the engineers or architechts who by necessity do not have a thorough training in these domains is a fundamental problem of all energy savings efforts, and merits thorough consideration within the context of a national plan.

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CHAPTER II

RESEARCH AND DEVELOPMENT IN THE AREA OF THE BUILDING AND ITS PASSIVE COMPONENTS

A distinction can be made between the passive attributes of a building (quality of insulation, position and quality of windows, integration into the local climate, etc) and its active attributes (the heating plant, ventilation system, etc). In order to facilitate the exposition of the research in this area, we have consequently distinguished between the passive components, which will be analyzed in this chapter, and the active components, which will be analyzed in the next chapter. We will first discuss the problem of windows, then the insulation of the building shell, the spectrally selective external coatings which diminish radiation losses, and finally the problem of the building's thermal mass. Although, in a strict sense, passive solar energy should in fact be considered outside the scope of an energy savings exposé, we give, nonetheless, some information that appeared to be interesting.

1) Windows: transmission and infiltration losses

In a typical house, thermal losses through windows are on the order of 30-50% of the total. In the case of a well insulated house, this fraction is likely to increase unless the thermal performances of the windows are improved. For this, four aspects are taken into consideration:

- The heat transmission coefficient k of a double-glazed window within a wood frame of the type currently used is approximately 3 W/m^2K or practically ten times more than the transmission coefficient of a well insulated wall.
- Badly sealed window interfaces can be an important source of non-controlled air flows.

- In a dwelling, the window is one of the most important comfort elements; it allows daylight to enter, it assures a visual contact with the outside, it allows for the direct, individual and natural ventilation of apartments.

- Finally, the window allows for an interesting solar energy contribution which can, even in winter, compensate for losses.

The importance of the problems posed by windows has motivated the IEA to organize a seminar concerning this building element in Holland in June 1980. The summaries of the Swiss participants at that meeting raise the following points (82):

- The frame, depending upon how and of what material it is made, can represent an important thermal bridge, and should be perfected in parallel with the development of new panes.

- From among the diverse types of available seals, "O-rings" seem to be the most effective.

- As for the glass and the number of pane surfaces, the current trend is oriented toward vacuum-sealed double-glazed windows and using glass with selective layers. Only one combination of this type achieves transmission coefficients comparable to those of super-insulated walls ($k < 0.3\ W/m^2K$).

- The problems posed for the realization of super-insulated windows are numerous:

  . achieving selective surfaces of very low emissivity;
  . maintaining a good vacuum ($< 10^{-4}$ mm Hg) for a number of years;
  . developing window frames having thermal characteristics comparable to those of the window;
  . fabrication costs.

Several research projects on windows are being carried out in Switzerland.

- A Lausanne-based industry is studying the feasibility of double-glazed evacuated windows (83);

- The EPFL is establishing a solar test station "STETSO" which will in particular allow the study of windows (82);

- At Zurich, a research project is examining the advantages and inconveniences of evacuated double-glazed windows for buildings (83);

- Results of the EPFZ show that with an appropriate selective coating, it would be possible to reduce in principle a window's thermal losses by a factor of two while conserving a good transparency to both the daylight and the sun's heat. Such a window would have certain characteristics of a type of "thermal diode". In effect, it would be transparent to the heat of the sun but opaque to infrared rays of greater wave-lengths which would tend to escape from the inside of the heated room. This type of selective coating can therefore pose problems in summer and necessitates the installation of an active control system which would match the properties of large glazed areas to the summer/winter or day/night conditions (84).

2) Materials and the thermal insulation of the building shell

The research and development on new insulating materials is being carried out mainly in industry. The only studies in the framework of the Swiss university structure are at EMPA (85) and concern the properties of wood, and at the EPFZ which has a project on the fabrication of thermal insulation from recycled glass (86).

Concerning thermal insulation techniques, there are particular problems in the areas of thermal bridges and condensation risks.

Thermal bridges are construction zones where weaker insulation causes greater heat losses and a localized decrease in temperature. The thermal bridges appear mainly at the joining points where floor meets wall, and diverse research is in progress with the goal of minimizing their contribution to heat losses (87).

Condensation problems are found more frequently in the neighborhood of thermal bridges as well as at the surface interfaces of differing materials such as the walls and the insulation that covers them. These internal condensations are particularly detrimental to the building's longevity and do not appear in general in homogeneous walls. In the case of a high degree of thermal insulation, there is thus a good case for making a detailed examination for possible, eventual condensation and to install, where necessary, a vapour barrier on the warm side of the wall. Several research projects on condensation and vapour barriers are in progress in Switzerland, specifically at the EPFL (88).

EMPA and the laboratory for building materials of the EPFL do measurements on the thermal, mechanical, hygrothermic, etc. characteristics of different building materials. These measurements are done with the particular goal of certifying the properties of these materials and verifying their compatibility with the current regulations. Diverse measurement apparatus are at the development stage in university institutes, particularly for the measurement of thermal conductivity of materials and systems such as walls (33).

In the construction of new buildings it is in principle easy to use existing materials to obtain a high degree of insulation. In the case of thermal retrofit, problems still exist and difrerent solutions are proposed.

From the thermal viewpoint, it is distinctly more favourable to apply a supplementary insulation to the exterior rather than the interior of existing walls: thermal bridges are eliminated, condensation risks are less, and the thermal capacity of the walls is utilized to a better advantage. Because of some other advantages in addition to those previously cited, the external supplementary insulation of walls is becoming more and more the accepted method for thermal retrofitting (89).

3) The decrease of radiation losses of opaque surfaces

The phenomena which occur at the wall surface and, in particular, thermal exchange between solids and the surrounding air, are among the most complex of building physics. In these processes, the thermal radiations absorbed and emitted by the surfaces, as well as the neighboring convective air movements, play an essential role.

A group of researchers of the EPFZ is studying the influence of the thermal emission coefficient of building exterior surfaces and windows on the energy consumption (84). The calculations indicate that, in principle, a reduction in consumption of the order of 15% is possible by the use of a

selective surface in the form of a coating or of a paint on the building surface. Such a reduction in energy consumption is equivalent to 3 cm of supplementary insulation. In some thermal retrofit situations such a coating will lead to a reduction in the thickness of supplementary exterior insulation required. Unfortunately, it is still not possible to know if the manufacture of such coatings would be economically competitive.

In the areas of materials and insulation techniques as in the area of exterior walls insulation techniques, in principle, discoveries are still possible. A possible example is the development of building elements of variable thermal conductivity (90) which would permit the control of gains and losses to the ground or the atmosphere as a function of the time of day and the meteorological conditions.

4) The thermal mass of buildings and heat storage

The heat capacity of building materials allows the storage of some quantity of heat in the building shell. If the structure is "heavy", meaning that the walls and foundations are thick, the building's thermal mass will be large and therefore capable of accumulating a significant quantity of heat. This stored heat creates a thermal inertia which attenuates the effects of abrupt variations in the outside temperature, improves comfort, and decreases the maximum power required from the heating plant, but also prevents a rapid reheating or recooling of the building.

Numerous research projects have been completed in the last few years in order to determine the influence of thermal mass on energy consumption for heating and air-conditioning (91).

- For buildings heated continuously, the annual energy consumption is the same (to a few percent) for both heavy and light structures.
- For buildings heated intermittently (night temperature set back, for example), the possible energy saving is on the order of 10% for heavy structures and 20% for light constructions.

5) Some notes on bioclimatic architecture and passive solar

Bioclimatic architecture and passive solar are actually outside of the scope of this work. We have nonetheless included some of the information that we thought to be interesting.

From the architectural perspective and the study of building physics, it is without doubt that the most important recent developments concern solar architecture. With the help of very detailed computer programs, it is now possible to simulate and optimize the passive solar gains of buildings by accounting for local meteorological data, such as sunshine, precipitations and wind.

In the United States, according to an estimate by the Department of Energy, there currently exist between 10'000 and 20'000 solar houses and this figure is expected to exceed a million by the mid-1980s.

In Switzerland, a coordination concerning passive solar architecture has been initiated by EMPA (92). In the preceeding chapter several Swiss projects were described in which there was a passive solar contribution.

Just as the sun's heat can be used to decrease the building's heating load, it is also possible to benefit from the temperature of the ground. This is, at a certain depth, on the order of 10 to 15°C during the entire year. It is also possible to take advantage of the ground's coolness, for example, in order to cool the building in summer (93). One non-conventional suggestion is the construction of underground dwellings whose roofs would be exposed to the sun for the natural lighting and the passive solar heating of the house. A calculation indicates that such a "cave" could be heated for the entire year, but would consume less than a third of the energy of an identical, conventional house above ground (94). Even if this proposition is not acceptable from either an economic or social point of view, this demonstrates nonetheless the advantage of using the earth as a natural insulant which absorbs the outside temperature fluctuations both in summer and in winter.

The simultaneous consideration of the possible uses of the solar contribution and the earth could lead to encourage the construction of "low-rise" buildings with large surface areas (95), but this would, of course, pose other problems.

An important characteristic of passive solar structures is their capacity to store the sun's heat or the night's coolness in their walls and floors. An extension of these ideas is to use passive or active systems to store the natural heat or cold. An administration complex with a useable office space of 17'200 m^2, constructed in the United States according to these principles, consumes less than 180 MJ/m^2 (96). In this project, even though a large part of the building volume is underground, lighting is essentially obtained from daylight.

A group of 50 passive solar houses have been constructed in Canada between 1977 and 1979 (52). These houses have an average energy index for heating of 220 MJ/m^2 for a climate with 6000°C days, which is essentially that of Davos ! The houses are very well insulated, and the uncontrolled air infiltrations are extremely reduced. Ventilation is provided by an air to air heat exchanger which recovers nearly 70% of the heat in the stale air. The structure is relatively light and the south facing window surface which provides the solar gain is only 6% of the heated floor surface. With such a window area, the overheating problems in summer, as well as the losses at night, are limited. These wood houses of weak thermal inertia are typical examples of direct gain solar passive systems.

From the viewpoint of passive solar architecture, high-rise apartment or office buildings pose interesting problems which should still be studied. There are, however, already some isolated examples:

- A 14-storey office building was completed in 1979 for IBM in Detroit, It has a limited window area, but the essential illumination is however provided by natural light. In addition, the building surface are such that the solar gain is maximum on one side and thermal losses are minimum on the other side (97).

- The world's largest solar building is soon to be completed in Singapore. It will have 40 floors and consume 38% less energy than a similar, conventional structure (98).

Concerning the possibilities for passive solar in Switzerland, one interesting peculiarity of the building stock is the important thermal mass of the old buildings and of those to be renovated. The addition of a greenhouse or a Trombe wall on the south face of the building enables the capture of solar energy and then storage in the facade. This technique has been used particularly in the United States for the thermal improvement of small factories and warehouses (99).

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CHAPTER III

HEATING, AIRCONDITIONING, LIGHTING AND VENTILATION TECHNIQUES

1) Energy control and energy accounting in buildings

It often occurs that entire apartments or rooms in an apartment are only occupied for brief time intervals. Significant energy savings could be obtained by reducing heat, ventilation, airconditioning or lighting in these locations during these periods. Another important source of possible savings is the automatic regulation of energy contributions to a given room as a function of the occasional or unanticipated supplementary energy gains: people, isolation, machines, etc. Finally, it is generally thought that individual energy accounting could be a means of encouraging consumers to save energy.

It is common to all of these ideas that they necessitate:

. measurement devices which enable the determination of local conditions and/or the energy flows in a given zone;

. control devices which enable the opening or closing of circuits or on/off position of apparatus;

. decision-making devices which enable the programming or the regulation of a given system's operation.

In all of these areas it appears that electronics can play an important role, on the condition, however, that the problems posed by the electro-mechanical interfaces (measurements transducer, remote controlled values etc) could be resolved both from the technical and economic points of view.

Simpler devices, based on thermomechanical principles, can also perform similar functions. This is especially the case with thermostatic valves which control the thermal emission of a radiator by adjusting the flow of hot water as it is actually needed.

According to the state-of-the-art in this area two or three years ago, it could be affirmed that these thermostatic valves would contribute savings on the order of 10-20% (100). However, it is necessary to be prudent when generalizing these results, because it is often that several energy saving measures are implemented simultaneously. For example, in one experiment in the canton of Geneva, half of a group of 4 similar buildings were equipped with both thermostatic valves <u>and</u> heating consumption monitors (81).

These experiments undertaken on thermostatic valves are in fact not always conclusive, especially because of the influence of inhabitant behavior and the secondary effects of the valves on the operation and overall equilibrium of the heating system. An example is a Swedish experiment in which three apartment buildings of 64 apartments each were equipped with thermostatic valves and two similar buildings were used as control (101). After optimum regulation of the heating system in the five buildings, detailed measurements showed that the buildings equipped with the valves consumed in fact + 10% more energy than the control buildings !

Another experiment in Sweden concerning 4 groups of 100 to 1'000 houses each showed that in one case the consumption had increased by + 5% and that in the others it had decreased by -4, -7 and -7.5% (102). Diverse studies are currently in progress in order to determine the origin of these contradictory results (103). These studies are examining in particular the influence of thermostatic valves on the equilibrium of the distribution system.

As it relates to large commercial or office buildings, the savings obtained by sophisticated control systems using computers instead of classical methods (a night watchman to extinguish the lights, a janitor to lower the heating temperature during the week-ends, etc) are of the order of 20% (104).

In private residences or collectives, only a few truly conclusive experiments using elaborate control systems have thus far been reported. However, simulations done in the Nordic countries indicate that the potential savings offered, especially by the intermittent heating of dwellings, is on the order of 15 to 20% (105). The principal problem posed by intermittent heating is that of condensation and thermal inertia. It seems that it would be difficult to go below 10^{o} if the intention is to avoid these problems and that the dwelling-types should have a low thermal inertia (106, 91).

Simple systems in which individual rooms are maintained at constant but different temperatures, according to their function, enable the attainment of substantial energy savings. For example, 600 highly insulated houses have been constructed in Scotland in 1975/76 (49). In these electrically heated houses, living room temperature is kept at 21^{o}C while bedrooms are held at 15.5^{o}C. The total energy consumption of these houses, in which approximately a third is for heating, is on the average of 360 MJ/m^{2}.

For the programming of simple central heating systems as a function of a weekly schedule and the hours in the day, some houses recommend apparatus which enable the saving of 10 to 15% with respect to more classical systems such as time-switches (107). With these systems it is possible to adjust temperature of the water used for heating as a function of the outside temperature and the desired inside temperature. This technique enables the optimization of boiler efficiency which is best when the water temperature is lower.

Within the framework of the IEA, Sweden is preparing a study on individual temperature control systems for the rooms of an apartment.

The systems discussed above concerning local temperature control and regulation are generally sufficient for the buildings in which the problem of heating cost allotment is not an issue. The metering of energy consumption becomes an important consideration for houses connected to disctict heating network and rented apartment buildings. In this case, for heat accounting, three groups of methods can be distinguished (108):

- <u>Heat meters</u> which can, in principle, be calibrated. Their operating principle is based upon the temperature difference between incoming and outgoing water combined with a measurement of the flow. The precision of these apparatus is on the order of 1% (109), but this figure is given by the manufacturers and has not been confirmed by independent measurements.

- <u>Heat monitors</u> based on the principle of <u>evaporation</u>. They are mounted on radiators and their use is consequently limited to this heating system. These inexpensive devices should be adjusted to local conditions and can only yield a relative measurement. A German study claim that for suitably constructed and properly installed heat regulators, the maximum cost distribution error is between +2% and -5% (110).

- Heat monitors based on measured temperature differences: the room temperature minus the outside temperature or the temperature gradients inside the radiator body. One simplified variation of this method consisted in measuring the temperature of rooms and using this as a heating cost allotment base (111).

These measurement systems can in general be combined with control mechanisms which enable the adjustment of the rooms to the desired temperatures (108). In the case of electric heating, this type of installation is in principle particularly easy to realize, and one has discovered, however, that there were still numerous technical, socio-economic and legal problems remaining unsolved concerning individual energy accounting for heating. Certain experiments indicate that in apartment blocks, recording of the effective temperature (111) is perhaps just as "acceptable" as direct billing for the heat provided to each tenant. The major inconvenience of such a "universal" system is that it does not correctly account for the ventilation habits of the tenants. It appears once again that "fresh air" is one of the crucial parameters determining the limits of the control and conservation of energy in buildings.

At Lancy, in the canton of Geneva, a building has been equipped with hot water meters and heat monitors for the purpose of experimenting on individual energy accounting of heating costs (81). A comparable experiment is in progress at Geneva for the Cantonal Energy Commission.

The Swiss Movement for Energy Savings (SAGES) has recently published a brochure in which advice and practical examples are given for individual accounting of heating costs (124).

2) Classical central heating

Nearly 54% of the heating needs of Switzerland are provided by central heating plants. In these systems all of the buildings' radiators are connected to a closed distribution circuit in which one pump circulates the water heated by one boiler. One of the dominant characteristics of central heating is its bad overall efficiency, which is on the order of only 50% for a typical installation. In order to understand this figure it is necessary to account for all the losses, namely the energy losses which even if they partially

remain in the building, are not used to create the desired thermal climate at the desired location. Five types of losses can be identified and from each a partial efficiency may be defined. If Q is the quantity of net energy required to heat the building, the overall efficiency will thus be written as follows (see Appendix II for the mathematical definitions of the terms):

$$\eta = \frac{Q}{Q + P_A + P_B + P_C + P_D + P_E} = \eta_A \ \eta_B \ \eta_C \ \eta_D \ \eta_E$$

A) Auxiliary losses ($\eta_A \simeq 0{,}97$): These losses correspond to electricity used by auxiliary apparatus such as the circulation pump and the burner motor.

B) Burner losses ($\eta_B \simeq 0{,}70$): These losses, due to incomplete combustion, the draft and the bad insulation of the boiler as well as to eventual oversizing, are analysed in detail below.

C) Control losses ($\eta_C \simeq 0{,}90$): Heating systems function in such a way that the burner stops when the given temperature is attained. At that moment, the temperature continues to rise above the desired value.

D) Distribution losses ($\eta_D \simeq 0{,}90$): The lost heat in the distribution network contributes in part to the heating of empty shafts, ventilation gains, cold water pipes, etc.

E) Emission losses ($\eta_E \simeq 0{,}95$): A part of the emitted energy serves to overheat the air in neighborhood of the radiator.

The order of magnitude given above for the partial efficiencies correspond to reasonable averages for typical systems (112). Their product gives indeed an overall efficiency on the order of about 50%.

Oil and gas central heating plants are currently the objects of several research projects, both in and outside Switzerland. At Lausanne, results concerning the efficiency measurements of modern heating plants for large apartment buildings have been recently published (113). The authors of that study define the efficiency η_{AB} in the following manner:

$$\eta_{AB} = \eta_A \eta_B = \frac{\text{net energy in the outgoing hot water}}{\text{combustible energy + electrical energy}}$$

Measurements taken for a period of one year indicate that η_{AB} is on the order of 80 to 85%, but that during summer the efficiency is only 65% for the making of hot water. These figures show that heating systems, even when well tuned, are generally over-sized because the theoretical efficiency of a boiler at full load is easily greater than 90%. One of the conclusions of the Lausanne study is that the use of combined boilers for the making of domestic hot water and heating should be avoided. The use of an independent plant for the making of hot domestic water should, according to these authors, enable an energy savings on the order of 1 to 3% (113). This figure has to be compared with the statistics (114) on the energy indices which give indices on the order of 1000 MJ/m^2 for rented buildings with combined boilers and 910 MJ/m^2 for buildings using an electric boiler for the making of hot water. The corresponding figures for villas are, respectively, 986 and 915 MJ/m^2, also yielding a 10% difference.

There are principally two types of boiler losses:

- The boiler efficiency itself which accounts for losses related to the principle of the system itself such as the incomplete combustion of the oil or gas, the heat lost through the chimney, and that which is given off through heating the boiler-room;

- The use efficiency, which accounts for, among others, the losses related to the intermittent functioning of the boiler. In effect, when it stops running, the chimney's natural draft re-cools the boiler which has to be reheated anew when re-started in order to attain its maximum efficiency. This effect is particularly important if the boiler is oversized, and it explains the bad overall efficiency of existing heating systems.

Several studies are in progress in Switzerland with the goal of increasing the efficiency of boilers, particularly in the case of intermittent operation. A study of the Institute of Thermodynamics and Burners (ITV) of the EPFZ summarizes the situation and the possibilities in central heating in the form of the following table (115):

A : Reasonably well installed classical central heating

B : Very well installed classical central heating

C : Central heating equipped with an advanced boiler which functions continuously and is automatically regulated

	Boiler efficiency		
	Actual efficiency	Use efficiency	η_B
A	81 %	86 %	69 %
B	92 %	95 %	87 %
C	97 %	∿ 100 %	97 %

There is also research in progress in industry and oil or gas boilers with efficiencies on the order of 90% are already available on the market (116).

Efficiency measurements of heating plants are in progress at Zurich (125) and at Geneva (126). These measurements are less detailed than those of Lausanne but pertain to thousands of installations. At Zurich, it is reported that out of 600 installations inspected more than half were oversized by a factor of 3 or more (127). At Geneva, 28% energy savings have been realized between 1973 and 1979 by a set of energy saving measures in the buildings belonging to the city, notably by decreasing the temperature of certain rooms, but also by ensuring a regulation and optimum maintenance of heating plants (81).

At EPFL, one research project has just begun on the losses involved in the circulation and in the distribution of hot water (68).

An information campaign is currently being organized at the national level by the Swiss Society of Energy Savings (SAGES), the Swiss Action Committee of Economic Heating and the Federal Office of Energy, in order to improve the overall use efficiency of heating plants.

3) Other heating systems

Admitting the necessity to find alternatives to traditional oil-fired heating systems, it is not easy to evaluate the respective advantages and inconveniences of proposed new solutions. In this context, three types of problems can be defined:

a) What is the optimum combination of substitution and energy saving measures that ensure a maximum conservation of energy? For example, is it to construct solar houses, use heat pumps, or simply super-isolate the buildings and use advanced oil heating systems, or electrical heating?

b) What is the "best" heating system for a building in a given region? Is it central heating or district heating? What forms of energy should be chosen? What is the best combination when a binary system is required? For example, solar/oil back-up, heat pump/electric back-up,...?

c) What is the "best" heating system for a room or an apartment in a given building? For example, central heating or apartment by apartment, by radiators or convectors, at low or high temperature, in the floor or in the ceiling, by heater or with hot air?

All of these problems are not well studied and there is a need for theoretical and experimental research.

a) heating system comparisons

The problem of comparing the respective merits of diverse heating systems is of such a complexity that several experiments are in progress in which similar buildings were equipped with different systems. For example:

- The renovation on "Limmatstrasse" in Zurich enables the testing of a whole series of systems installed in different buildings: classical central heating, heat pump, individual accounting and regulation of the consumption (17).

- The PTT is in the process of equipping eight telephone centrals with four different heating systems: oil, electricity, heat pumps, solar collectors (117).

- In Sweden, a large scale project comprising 41 experimental houses is now in the evaluation phase (61). Four basic systems are tested in these houses: solar heating, ventilation with heat recovery, advanced control (systematic

variation) of the indoor climate, heat pumps. Seven possible combinations with these systems have been implemented in several houses and can thus be compared.

- In a Danish experiment, a given room has been heated with nine different heating systems(118). The measurements indicate differences in heat loss on the order of 15% through the window and 20% by infiltration. The most economical heating systems seem to be those in the floor and by radiators, and the least economical are those with convectors and with hot air. The differences are explained by the fact, among others, that in hot air and convector systems the moving air mass has more of a tendency to re-cool itself in the proximity of cold surfaces, such as windows.

- In Belgium, the emission efficiency of radiators and convectors has been measured under real conditions (179). An efficiency of 87% has been found for convectors and of 81% for radiators at an incoming/outgoing water temperature difference of 30°C. This result seems to be in contradiction to the conclusions of the preceeding Danish experiment (118).

Other research approaches the system comparison problem from the theoretical angle. These studies are in the form of "integration exercises", meaning simulations in which a large number of possible options are compared by integrating a maximum of known givens. One such integration exercise has been recently completed for the Belgium government (112). For a small one family house, comparisons have been made from among eleven different systems, including classical central heating, warm air heating, electrical heating, heat pumps, and solar collectors of different kinds. A detailed economic analysis has shown that from among all of these systems, the most economically advantageous still remains the classical central heating, under the condition that the house is well insulated. The bad economical attractiveness of the solar alternatives considered in this project seems to be partially because of the consumption of the electrical auxiliaries (pumps, ventilators, etc).

In Switzerland, a theoretical study on the substitution of individual heating by other heating methods has been done by the Institute of Thermodynamics of the EPFL (119). The same institute, within the framework of a recently published comprehensive study on heat pumps (120), makes a comparison of four heating techniques for an entirely new hypothetical agglomeration of

400 individual houses, 100 rented apartment blocks and 10 large administrative and commercial buildings (121): a collective heating arrangement using a bivalent heat pump/light oil boiler seems to be economically twice as advantageous as individual electrical heating in each building. Finally, a comparison of the economic attractiveness of the diverse heating systems for well insulated buildings is being done by an engineering office in Baden (122).

In the state of the discussions on the objectives of Project X of the IEA, it appears that it is tending toward the running of a certain number of "integration exercises". Taking a specific case, it is possible that the Vetlanda house and the building at Glasgow, which are instrumented and for which experimental data exist, will be taken as a point of departure for diverse simulations.

b) technical developments

Numerous technical developments are being studied in the attempt to increase the efficiency of classical systems and to develop alternative systems. We will not, in this report, discuss the development of these new systems (heat pumps, cogeneration, solar heating), and will consider airconditioning systems in the following paragraph. We will thus restrict ourselves to mentioning some developments concerning non-central heating systems.

- Room-by-room heating: generally speaking, the direct heating of occupied rooms has, in principle, clear advantages from the point of view of energy conservation. More specifically, it enables the direct adaptation of available energy to needs, it facilitates individual energy accounting, and removes the distribution losses inherent to central collective or district heating systems. These advantages have been well recognized for electrical heating, but exist also for other systems using wood, coal, oil or gas. In this area, interesting developments have occurred with room-by-room heating with gas, notably in France (129). As back-up heating for solar systems or others, it is important to develop new, highly efficient small heaters using various energy agents. Finally, fundamental research should be undertaken in order to study the feasibility of catalytic combustion radiators which would permit, in principle, a maximum energy conservation.

- Local heating: As much from the viewpoint of comfort and the possibilities of individual regulation, as that of energy conservation, local heating is very interesting. It consists of creating a thermal "micro-climate" at the specific location of occupancy. Thus, what is particularly being studied is the use of heated chairs in offices or workshops at a reduced ambiant temperature (130). One could even envisage heated clothing.

4) Air conditioning, ventilation and heat recovery from stale air

Air conditioning and hot air heating systems are reputedly wasteful from the perspective of energy conservation. This is due in particular to the low efficiency of the heating and re-cooling apparatus which is limited to 85-90% for technical reasons. However, in certain cases, the air conditioning plants are necessary, notably in large service buildings. Similar to classical central heating systems, important progress in the area of air conditioning plants is difficult. This is why the most interesting developments in the areas of air conditioning, hot air heating and ventilation concern air-to-air heat exchangers which in the current technical state-of-the-art enable the recovery of 60 to 80% of the heat from stale air to be expelled from the buildings. The heat exchangers can be used in three main circumstances:

. to recover the heat lost at the boiler chimney and the ventilation in large buildings;
. to recover the heat (or cold) in the air conditioning systems of large commercial, industrial or sports complexes;
. to recover the heat lost by controlled ventilation in low energy consuming dwellings.

Seing the importance of all these applications, numerous research projects are in progress on several levels:

- In the framework of *Project III* of the IEA which is making a study on energy recovery in ventilation systems (131);

- Outside of Switzerland, diverse research projects pertaining to the study of air-to-air heat exchangers, in particular with respect to low energy consuming houses (132);

- At the Institute of Applied Thermodynamics of the EPFL, studies are being done on heat lost by air curtains (68) and the performances in actual service of rotating energy recuperators in ventilation and air conditioning installations (133). Efficiencies higher than 90% have been measured for short utilization periods and on the order of 85% for longer periods of up to 3 months;

- At Geneva, one study on the heat recovery in rented buildings, done for the Cantonal Energy Commission, is trying to determine the viability of heat recovery from expelled air as much from the technical viewpoint as from its energy and economic attractiveness.

In Germany, one study has been published on the potential of the implementation of systems for the recovery of heat conventionally lost through ventilation and for the preparation of hot water (134). This potential is 15% for existing buildings and 30% for new buildings.

We have already noted the advantage of very air-tight buildings with regard to energy conservation. These buildings have then need of a mechanical ventilation system. This poses the question of the energy demand and the overall economic attractiveness, especially concerning large buildings. The results of a detailed comparison of a mechanical ventilation system relative to natural ventilation for a rented building (135) are decidedly in favor of central mechanical ventilation with heat recovery. The energy consumption is decreased by half when the annual cost of ventilation, including amortization and plant maintenance, only increases by 10%.

The performances of ventilation and heat recovery systems clearly requires reasonable inhabitant behavior, especially when they have the possibility of opening the windows. Through measurements, on a naturally ventilated, traditionally constructed English house, studies have shown that the average rate of 0.4 air changes per hour to ventilate the entire house increases to 3 air changes per hour when the window of the bedroom is fully opened (136). The resulting measured energy use increase for heating was of the order of 64%.

The larger the volume V of the building, the more its energy consumption becomes a function of ventilation. For a given insulation level, this comes from the decrease of the ratio A/V (see Appendix II) to which is added, in the case of high-rise apartment buildings, the chimney effect. The inside/outside pressure difference due to this effect causes supplementary air infiltration which can be reasonably reduced by an appropriate balancing of the mechanical ventilation system (183). The distribution of the differences of pressures in a large tenant apartment building also depends upon the closing and opening of windows. It is thus important that the central ventilation systems should be studied with the idea of minimizing these interactions.

One aspect of domestic comfort which is often neglected with regard to air conditioning and ventilation systems is noise. In this respect, when most of the new heating systems are essentially silent, the advent of forced ventilation systems with heat exchangers to maintain the air quality and to conserve energy, should be particularly well studied from the perspective of both noise and vibrations (137). A possible technique which enables an elegant resolution of this type of problem is based on the use of passive heat exchangers-ventilators, which involve the transfer of latent heat across a porous membrane. These systems are available in Japan and have an efficiency on the order of 75% (132).

5) Domestic hot water and heat recovery from used water

The use of domestic hot water, just as the ventilation habits, is extremely dependent on the life-style and family structure of the occupants. In proportion, as the fraction of household energy consumed for heating diminishes, the fraction apportioned to the hot water and the household appliances becomes more important. In the case of super-insulated houses, the preparation of domestic hot water for a year can constitute a more important energy expense than heat. For these reasons, two remarks are particularly important:

- If the solar energy is not sufficient to satisfy winter heating needs, it can nevertheless be used in our climates for the preparation of hot water. This solution was a very widespread practice in the USA at the beginning of this century, and several pilot-studies and research projects in Switzerland (117) demonstrate its advantages and its high attractiveness;

- Domestic hot water heating can be recovered by heat exchangers.

Several studies on heat recuperators from used water are in progress in Switzerland (138) and in other countries (139). The efficiency of water-to-water heat exchangers can be on the order of 80%.

New concepts for the making of hot water are also in the process of making their appearance. For example, The United States Department of Energy has developed a household water heater which uses a heat pump and of which the consumption is only half of that of a typical electrical resistance heater (180). Another idea consists of combining a freezer and an electric water heater in a single device capable of simultaneously providing the refrigeration needs and the hot water necessary for a household (126, see also IV.4.a)).

An important problem which not only concerns domestic hot water but also hot water for heating is that of its distribution through pipes.

In this context, interesting studies are in progress on the thermal insulation of pipes and in particular on the possibility of developing new plastic pipes for hot water (140).

A related problem which can be a non-negligible source of losses in large buildings is that of "thermal short-circuits", meaning the thermal coupling between the hot and cold water pipes, such that on certain floors the hot water is not hot, and the cold water is not cold!

6) Electrical and natural lighting

The problem of artificial lighting viewed in the energy conservation perspective consists of providing light which is agreable to the eye, and thus having a well defined frequency spectrum, with as large an efficiency as possible. For the three most important types of lamps, that efficiency, expressed as the percentage of electrical energy transformed into visible light and expressed in lumens per watt is the following under the best conditions (141):

Efficiency of electric lamps

	%	lumen/watt
Incandescent lamp	7	17.5
Fluorescent lamp	23	80
Sodium lamp	36	183

The sodium lamps giving a yellow light are not suitable for general lighting, and only fluorescent lamps offer a practical substitute for filament incandescent lamps. The potential energy savings expressed by the factor 80/17.5 is reduced by between 10 and 20%, however, by the inefficiency of the auxiliary electric equipment (ballast) which is necessary to maintain the fluorescence bur represents nonetheless a factor of 4 at least. The main problem posed by the substitution of incandescent lamps by fluorescent lamps is that of miniaturization. It is, however, already solved. The technical characteristics of a lamp that will be commercialized in the middle of 1981 are the following (142):

Comparison between filament and miniaturized fluorescent lamps

Technical data	fluorescent	filament
Average life time (h)	5'000	1'000
Nominal consumption (watts)	18	75
Luminous flux emitted (lumens)	900	900
Efficiency (lumens per watt)	50	12
Color temperature (Kelvin)	2'900	2'700

Obviously, these new lamps will be more expensive; however, because their life-time is five times longer and their energy consumption smaller, their initial price is quickly compensated.

The efficiency of current ballasts for fluorescent lamps is on the order of 70-75% for the standard models, and about 80-85% for the improved models (143). With the goal of increasing that efficiency, as well as decreasing the ballast noise and obtaining a continuous regulation of the luminous flux, ballasts with electronic circuits functioning at a frequency around 20 kHz are under study. The efficiency of these ballasts being in the neighborhood of 100%, energy savings on the order of 20% have been measured in a large scale experimentation of a prototype in the USA (144).

In large commercial and administrative buildings nearly 50% of the energy consumption is devoted to lighting. Given the low energy efficiency of electrical lighting, more than 75% of energy for lighting ultimately goes toward heating the building, which contributes to an increase in the building's summer cooling load (145).

In order to diminish the electrical consumption of artificial lighting, a considerable number of measures are possible:

- Substitute incandescent lamps by fluorescent lamps;
- Reduce the level of lighting (lumen/m^2) wherever this is possible;
- Install luminous flux control systems piloted by photo-electric cells in order to modulate the artificial light as a function of the natural light contribution;
- Discourage general lighting in order to replace it with individual lights;
- Install time-switches and controls in order to extinguish or lower the light when it is no longer needed;
- Rely on natural lighting as much as possible.

The use of natural lighting for the interior of large buildings is currently the subject of some major research (146). Just as solar heat can be used for the heating of the ground temperature to decrease the thermal loads, the use of solar light for the lighting in a building's interior offers significant possibilities for both comfort and energy conservation. More specifically, natural lighting is recognized as important because of the well known affinity of the human eye for this type of light and the difficulty of reproducing its spectrum with artificial lighting. Natural lighting can be easily combined with solar energy systems. In effect, subsequent to the concentration of solar rays, components for the heating (infrared) and for lighting (visible) can be separated. The natural light can then be directed to the building's interior by optical means and diffused to the location where it is needed (147).

For the future, with the hypothesis of the development of adequate light guides, central sources of light using lasers can be imagined, on condition that the efficiency of the latter can be increased (148).

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CHAPTER IV

HOUSEHOLD APPLIANCES

The average annual electricity consumption of households is relatively well known, particularly in Switzerland, via the statistics published by the Union of Swiss Electricity Utilities (UCS) and by the energy indices compiled by SAGES. The energy indices show that this electricity consumption, which includes that of electric household appliances and lighting is on the order of 10 to 15% of the heating energy used (see Table IV). The average annual electricity consumption per household, given by the UCS for 1977 is 3'300 kWh/year (149). For the entire Swiss household sector, this consumption corresponded in the same year to 22.5% of the total electricity consumption of the country.

When one considers the potential of the energy savings possible for heating, one sees that the quantity of energy consumed by household appliances could become a more and more important share of the household energy bill. This is what appears in Table IV where it can be seen that in highly insulated houses, the electricity consumption other than for the heating is 20 to 30% of the total energy consumption. It is necessary to stress that a part (estimated at about 35% (150)) of the energy used for household appliances is dissipated in the form of heat and thus contributes to heating.

Several significant studies have been recently published on the possibilities of energy conservation in electrical household appliances. One of them, mainly concerned with Denmark (151), concludes that an electric-household consumption of 3'000 kWh/year could be lowered to approximately 1'000 kWh/year, without a reduction in comfort, and relying only upon technological improvements currently available. In the United States, the Department of Energy has published an extensive study which proposes minimum performance standards for household appliances using electricity or gas (152).

Within the framework of the IEA, *Project X* proposed by Belgium, considers in its entirety the problem of electrical consumption of buildings. This includes not only electrical household appliances and lighting, but also that of the different motors, pumps and equipment that serves the ventilation system, the circulation of water for heating, the operation of elevators, etc. For example, the motor of the hot water circulator in central heating operates during the entire heating season. The annual electrical consumption to which this corresponds is easily 5 to 10% of the total electrical consumption of a small residence (150). If this project of the IEA is accepted, it will consist of simulating completely equipped, occupied buildings and comparing from both energy and economic perspectives a large number of possible combinations by introducing for each of them the efficiencies of the different components, and, in particular, those of household appliances and service equipment. In the framework of this proposal, a preliminary bibliographical compilation on the electrical consumption of buildings has been published by the University of Liège (153).

In this chapter, we will principally focus on the household apparatus using electricity. The devices using gas should not, however, be ignored from an energy conservation view-point: technical improvements are also possible for these, and they offer interesting possibilities for substitution, especially in the kitchen.

1) Crucial factors determining the household's energy consumption

The analysis of household energy consumption is difficult because it involves a range of various apparatus for which the technical characteristics and the modes of utilization are very different. In the case of energy needs for heating and hot water, energy indices expressed in MJ/m^2 have been introduced and are currently more and more frequently used. A similar evolution is underway for the other household needs and this is leading toward the definition of "energy efficiency factors" for the household appliances. These enable the manufacturers and users of these devices to compare their performances. The definition of these factors in a coherent fashion necessitates an investigation of the energy consumption structure of households. This structure is

generally analyzed as a function of three factors (149, 154):

$$(\text{consumption}) = \binom{\text{stock}}{\text{factors}} \times \binom{\text{use}}{\text{factors}} \times \binom{\text{technical}}{\text{factors}}$$

The stock factor is generally defined in the same fashion in most of the analyses and consists of the level of market penetration defined as the number of operating apparatus of a given kind per household or as the number of operating apparatus for a given population of households. On the other hand, the two other factors are usually defined in different ways depending upon the author and the type of analysis. For example, for the electrical appliance, the technical factor is generally the average installed power of the given kind of appliance, and for the use factor, the average utilization time per year of that installed power. This decomposition has the advantage of enabling a systematic analysis of household electrical consumption as a function of factors that are in principle easily measurable. In particular it is currently used for the statistical compilation on household appliances of the UCS (149) and of the UNIPED (155). The product of the use factor and the technical factor is generally called the specific consumption of the appliance. For electric household appliances it is thus usually written:

$$\binom{\text{specific}}{\text{consumption}} = \binom{\text{utilization}}{\text{time}} \times \binom{\text{installed}}{\text{power}}$$

$$[\text{kWh/year, appliance}] \qquad [\text{h/year}] \qquad [\text{kW/appliance}]$$

When the interest is to know the relative performances of different appliances of the same kind, the installed power is not always the best technical factor to take into consideration. For that reason, the energy efficiency of an appliance has been introduced as its characteristic technical factor. It is defined in such a way that the specific energy consumption can be written in the following manner (151, 154):

$$\binom{\text{specific}}{\text{consumption}} = \frac{\text{Amount of service provided (service/year)}}{\text{energy efficiency (service/energy)}}$$

The kind of service provided obviously depends upon the type of appliance (refrigerated volume for a refrigerator, laundry weight for a washing machine, number of listening hours for a radio, etc) and should be chosen in such a way as to provide a judicious definition of the energy efficiency factor. The energy efficiency factor, when introduced in this manner, and expressed as "service" per unit of energy, corresponds directly to the needs of the energy labeling from the viewpoint of the consumer's perception: the greater the energy efficiency factor, the greater the amount of service per unit energy provided by the apparatus. In paragraph 3) below we will make a review of some possible definitions for these energy efficiencies.

By rearranging the above factors with the definitions we are introducing, the following expression for the annual household energy consumption is obtained:

$$\text{Consumption} = \sum_i \frac{\text{stock}_i \ \text{utilization}_i}{\text{energy efficiency}_i}$$

and, for each kind of appliance i :

Stock : number of operating appliances per household;

Utilization : amount of service required per household and per year;

Energy efficiency : amount of service provided per unit of energy, or energy efficacy if the service provided is expressed in energy units.

The analysis of the consumption structure as a function of the three above parameters presents several interesting advantages:

- The numerator depends essentially upon socio-economic factors. The first term, the stock factor, depends primarily upon economic factors: rate of appliance stock renewal, relative price of appliances, publicity, etc. The second term, the utilization factor depends prinarily upon household characteristics: number of occupants, habits and preferences, etc.

- The denominator depends essentially on the technical performance of the appliances.

As we will see later in detail, a reduction of the household's energy consumption can be obtained by acting on these three parameters, either by decreasing the stock level and utilization factors, or by increasing the energy efficiency of the appliances.

2) Specific consumptions and utilization rate

Table II gives the annual specific consumption of some currently existing household appliances for Switzerland, some European countries and the United States. This table enables one to make some interesting statements.

- The specific consumptions are relatively similar for the European countries and the United States with the exception of refrigerators and washing machines for the latter country;

- The specific consumption of American refrigerators is decidedly higher than those of Europe because the American refrigerators are generally larger and are often equipped with diverse accessoires;

- The specific consumption of American washing machines is much lower than that of the washing machines used in Europe. This has its origin in the fact that in the United States the laundry is washed at low temperature and it is thus not necessary to heat the water as in Europe where the laundry is usually "cooked".

This type of comparisons show that the technologies used and the habits of appliance utilization are generally not very different for certain appliances. This enables the transposition of results concerning these appliances from one country to another. They also indicate that for certain domestic needs, such as laundry washing for example, radical solutions exist.

The Institute of Energy Economics and Planning (IENER) of the EPFL conducted a survey with detailed measurements in approximately 200 households in the Lausanne area (156). The goal of that research was to determine the specific consumptions and the level market penetration of electrical appliances used in households and to analyze the possible relations between this data and the socio-economic variables (revenue, number of persons in the household, professional levels). The average annual measured electrical consumption in that study is 2'400 kWh/year.

TABLE II

SPECIFIC ENERGY CONSUMPTIONS [kWh/year]

APPLIANCE	ENGLAND	BELGIUM	DENMARK	FRANCE	SWEDEN	SWITZER-LAND	USA
cooking stove	1200	655	950	1400	970	1400	1200
refrigerator	500	550	550	350	420	400	1583
clotheswasher	135	320	575	400	1000	780	83
dishwasher	850	720	650	450	830	410	361
television	195	180	165	150	140	135	444
lighting	300	530	300	700	880	400	2000

References : Switzerland (149,155); other countries (153)

3) Energy efficiency and energy labeling of household apparatus

The increase in the energy efficiency of household appliances is primarily an industrial problem which consists of manufacturing new appliances using techniques which are in principle currently available. According to the various studies undertaken, these conservation measures are economically attractive (150, 152) and thus provide the manufacturers with the possibility to renew the appliance stock. It is thus not surprising that the manufacturers should be the first to be interested as manifested by a statement of the Swiss Association of Manufacturers and Retailers of Electrical Household Appliances (FEA) at the occasion of a recent press conference (157). This type of attitude can be found in other countries and in Germany for example, the representatives of the domestic appliance industry have promised to the Ministry of Economic Affairs to effect a series of energy savings from now until 1985 (among others: refrigerators, 15-20%, dishwashers, 10-15%, etc) (158).

In order to efficiently replace old appliances by new, better performing ones to the satisfaction of both consumers and manufacturers, a significant effort to provide information is necessary. That information requires the collaboration of manufacturers, consumers unions, commercial organizations and certain governmental offices.

One of the first problems is the definition of energy indices for domestic appliances, for example as in form of the energy efficiency factors introduced in paragraph 1). The direct problem associated with the use of these efficiency factors is that of marking the indices on the appliances, currently termed as "energy labeling", in such a way that the consumers can easily compare and choose between different appliances. Numerous organizations are interested and concerned by this problem. The CEE has thus adopted a general directive which includes a list of appliances that should be marked in this way, as well as a directive applying to electric ovens (the two directives will take effect in 1982) (159). The basis of the energy labeling scheme proposed by the CEE consists of marking on each appliance the energy consumption in kWh measured under specific test conditions. The Consumers' Association of London conducted three interesting surveys for the English government regarding energy labeling; the consumer understanding of the labels, the verification of the correlation between testing methods and consumer use habits; the possible impact of energy labeling on consumer decisions (160).

Independently of the problems posed by the definition of energy efficiencies and their labeling, the major practical problem is that of the testing of appliances in order to officially certify their performances. The consumer's organizations insist on the fact that the tests should correspond to the actual household usage conditions of these appliances. The presentation format of energy indices should also be easily interpretable by the consumers, and the survey conducted by the Consumers' Association of London indicates that there is a decided preference for a label which displays a cost for a typical usage rather than the quantity of energy to which it corresponds. A revealing indicator of the difficulties posed by energy labeling and associated test methods is given by the Unites States which adopted a mandatory energy labeling system in 1975. That system has still not taken effect because it has not been possible to define in an acceptable manner the appliance test condition and the presentation of the result on the labels (161).

One aspect of the difficulties that we are raising originates from the fact that an energy label based on specific consumptions measured under given test conditions simultaneously involves technical factors and socio-economic factors related to the test conditions and the presentation of the results. Energy efficiency indices uniquely describing the technical performances of appliances enable one to avoid certain of these difficulties. This is for example the case of the energy efficiency factors introduced in the United States by the Department of Energy in order to specify to manufacturers minimum performance standards for household appliances.

	energy efficiency factors
regrigerators, freezers	$\frac{\text{refrigerated volume } [\ell \times \text{days}]}{\text{energy required per day } [\text{kWh}]}$
boilers, water-heater, cooking stoves, ovens,	$\frac{\text{heat transferred to the product}}{\text{total energy required}}$
clothes dryers, clothes washers, dishwashers	$\frac{\text{weight of the load } [\text{kg}]}{\text{Total energy required } [\text{kWh}]}$

The definition of these energy efficiency indices is consistent with other efficiencies currently used such as those of cars expressed in km travelled per liter of gas (miles per gallon in the U.S.) or electric bulbs expressed in lumen per watt.

4) Technical improvement possibilities for household appliances

In this paragraph we will review the possible technical improvements for the appliance in which the annual specific energy consumptions are the most important. These possibilities have been mainly studied at the Technical University of Denmark (150) and by the Department of Energy (DOE) in the United States (152). Only the improvements which in principle do not change the level of comfort provided by the appliances are considered.

a) refrigerators and freezers

In currently existing refrigerators and freezers, between 70 and 80% of the energy consumed is lost by transmission through the walls and the door. Despite this dominant characteristic, energy consumption is not a simple function of parameters like the volume because it also depends upon the refrigeration principle and, on accessories like automatique defrost and on details of construction. The studies show that the electrical consumption of refrigerators can be lowered by 50%, mainly by using an insulation thickness of 6-9 cm and increasing the surface area of the evaporator. The feasibility of this technique has been demonstrated by the United States Department of Energy by the reduction of consumption in a 500 l. regrigerator from 1'400 kWh/year to 600 kWh/year (180). A Danish study (150) shows that the consumption can be reduced to 1/5 of the current value by more radical measures including an insulation of 10 cm thickness and a tripling of evaporator and condensor surface area. The studies of DOE (152) led to similar results and both predict an annual consumption of 90 kWh/year for a refrigerator of 130 l. instead of the 550 kWh/year currently consumed. The major inconvenience of this type of radical measure is the greater outside volume as a consequence of the additional thickness of the insulation.

The same techniques enable similar results to be obtained for the freezers. In the case of radical measures, the thickness of the insulation is then expanded to between 20-25 cm. An indirect advantage of this supplementary insulation is that the time necessary for the temperature to increase from -18°C to -10°C in case of accidental power failure is on the order of 4 to 5 days.

A German constructor recently announced a freezer in which the condensor heat is used to prepare hot domestic water. One such freezer of 130 l. should thus be capable of providing 46% of the hot water necessary for a family of four. Relative to the traditional price of hot water, the payback time of the additional costs would be 2.6 years (128).

b) laundry and dish washing machines

The principal characteristic of existing European clothes washing machines is that only 10 to 15% of the consumed energy is used by the motor which is the element responsible for eliminating the hard manual labor of the washing. The remaining consumed energy is practically totally used to heat water. The comparison of the energy consumed for a given wash cycle by machines from different manufacturers shows that the energy consumption varies more than 50% from one to the other, also indicating considerable variations in the programs.

The energy conservation measures envisaged consider an increased thermal insulation, a reduction in the use of hot water in both volume and duration, and the possibility of a modification in the actual programs. A reduction of 50% of the consumption is technically possible but requires the elimination of the wash which does not even seem to be necessary if the main program is modified accordingly. For radical measures (150), it is possible to lower the electrical consumption to 1/8 of current levels. These measures consist of completely renouncing the electrical heating of the water and use the 50 to 60°C warm water produced by the central heating or by the domestic hot water system. The wash at that temperature, or even with cold water, is very widespread in the United States, and with modern detergents seems to give full satisfaction.

In Switzerland, the survey of the IENER (156) measured the energy consumption of different brands of laundry machines. The machines without water heating consumed the average 1/5 of the energy of standard machines. At EMPA, measurements are in progress on the consumption of water and electricity by washing machines (162).

Dish washing machines are in principle very similar to clothes washing machines. Similar conservation measures apply to them, and radical measures enable the attainment of a consumption at 1/7 of the current value (150).

c) clothes drying machines

There exist two types of clothes dryers: tumbler dryer and drying "closets". Although the first type of machine is widely used in certain countries like the United States, it is hardly used in Swiss households. The statistics of the UCS (155) claim on the other hand that 15% of the households have access to a collective drying space. For this type of appliance more than 80% of the energy is used to heat the air and the remaining by the drum motor or the ventilator of the drying closet. The possible conservation measures include the recirculation of a part of the heated air, the use of a heat recovery unit and the increase of the motor efficiency. The application of the set of these measures leads to an energy consumption that is 50% lower than the initial value (150). A reduction of electrical consumption up to 1/5 of the initial value is possible if, instead of heating the air at a temperature between 80-100°C, the temperature is restricted to the 50-60°C range of the domestic hot water of the heating system. In this case, however, the drying duration will be approximately 30% longer (150).

Another energy conservation possibility is provided by appliances which, instead of evaporating the humidity by heat, dehydrate the atmosphere of the enclosure by condensation (163).

Electrical consumption measurements of tumbler dryers are in progress at EMPA (162).

d) kitchen ranges and ovens

The goal of cooking on electrically heated plates or in an oven is to bring a given quantity of food to a given temperature and eventually maintain it there for a certain time. At the present state-of-the-art, only 15% of the energy consumed by the domestic ranges and ovens is in fact utilized to this end. Different proposed measures of conservation tend to increase that energy efficiency to around 30%, which, by simultaneously reducing the losses via a better insulation, results in a reduced electrical consumption for cooking by a factor of two (150).

More specifically for the ovens, the conservation measures consist in decreasing the size of the windows and the use of double glazing, increasing the thickness of the thermal insulation and decreasing the thermal capacity. A radical proposition consists in placing a smaller, well insulated oven, for the majority of usage, inside the standard oven.

It is interesting to compare, from the energy perspective, the electric ranges with the gas ranges. The energy efficiency of gas ovens is only 6% compared to the 15% for existing electrical ovens. On the other hand, the energy efficiency for the cooking in pots is 30% for gas compared to 15% for electricity. In the United States, the standard proposal by the Department of Energy is to bring the energy efficiency of gas to a minimum of 45% by 1986 (152).

e) lighting

We have investigated the conservation possibilities for lighting in the preceeding chapter. It can be claimed that the replacement of filament lamps by fluorescent lamps in situations where this is possible (approximately 80% of lighting needs) will lead to a 50% reduction in electrical consumption for lighting (151).

f) synopsis of proposed measures

Table II summarizes the effect of conservation measures proposed by the two main studies quoted in this section.

The American study (152) mainly considers the measures which can be undertaken essentially without modifying the appliances' overall mechanical characteristics and which act on the active components. For instance, they propose not to reinforce the insulation of apparatus above a certain level so that the wall thickness is not excessively increased.

The Danish study (150) proposes three levels of measures. The moderate and strong measures consist mainly in improving the existing apparatus whereas the radical measures require a conceptual modification of the appliance.

The two studies only envisage measures that are economically attractive and in particular the Danish study claims that the payback time for radical measures is on the order of 6 to 9 years depending upon the appliance.

Based on the anticipated results for the radical measures, a projection of the electrical consumption of a Danish household indicates that it could be 830 kWh per year, whereas the same household equipped with the best appliance available in 1979 would consume 2800 kWh per year (151).

TABLE III

TECHNICAL IMPROVEMENT POSSIBILITIES OF HOUSEHOLD APPLIANCES

		American study (152)		Danish study (150)				
		1978	proposed measures	1978	moderate measures	strong measures	radical measures	
refrigerators 411ℓ/220ℓ	EEF	220	634	146	233	402	892	ℓ/kWh/j
	CR	100	34	100	63	36	16	%
freezers 690ℓ/250ℓ	EEF	337	642	114	190	338	629	ℓ/kWh/j
	CR	100	52	100	60	34	18	%
clotheswashers	EEF	-	-	1.25	1.57	3.6	10.3	kg/kWh
	CR	-	-	100	79	35	12	%
clothesdryers	EEF	1.19	1.45	1.15	1.64	2.77	5.54	kg/kWh
	CR	100	82	100	70	42	21	%
electric areas 111ℓ/50ℓ	EEF	12	14	15	20	22	35	%
	CR	100	86	100	75	62	45	%
cooking with electricity	EEF	-	-	15	16	28	28	%
	CR	-	-	100	94	54	54	%
cooking with gas	EEF	31	45	-	-	-	-	-
	CR	100	68	-	-	-	-	-

EEF = energy efficiency factor
CR = consumption relative to existing appliance

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CHAPTER V

STATISTIC AND ECONOMIC STUDIES

If it is important to acquire a thorough knowledge of the whys and hows of the energy consumption of a given building, it is equally essential to have a general idea of the building stock, of its energy consumption, of its possibilities for thermal improvement, the associated costs and the economic attractiveness, etc.

1) Consumption statistics

In this area a very important project has been undertaken by SAGES (114) who was able, based on questionaires sent to building owners, to compile consumption statistics in terms of energy indices. The average value of the energy needed and domestic hot water is found to be 825 MJ/m^2 year (767 for individual houses, 825 for apartment buildings, 800 for schools, 800 for administrative buildings without air conditioning and 1100 for those with air conditioning). These values should be compared to those of pilot-buildings as we did in Figure II.

Three interesting conclusions arise from the details of the study: 1) the dispersion of the consumption is very large (for example, the number of houses with E smaller than 500 MJ/m^2y is almost nearly equal to the number of houses with E greater than 1000 and equal to one fourth of the houses with E = 850); 2) the correlation with the construction year is quite clear, the buildings constructed in 1965 consuming a good 1/3 more than the buildings constructed in 1940; 3) the consumption increases drastically with the installed power (in W/m^2), which clearly shows the effect of boiler oversizing. This oversizing is also illustrated by the average value of the installed power which is 150 W/m^2 although 60 to 80 W/m^2 are in general sufficient.

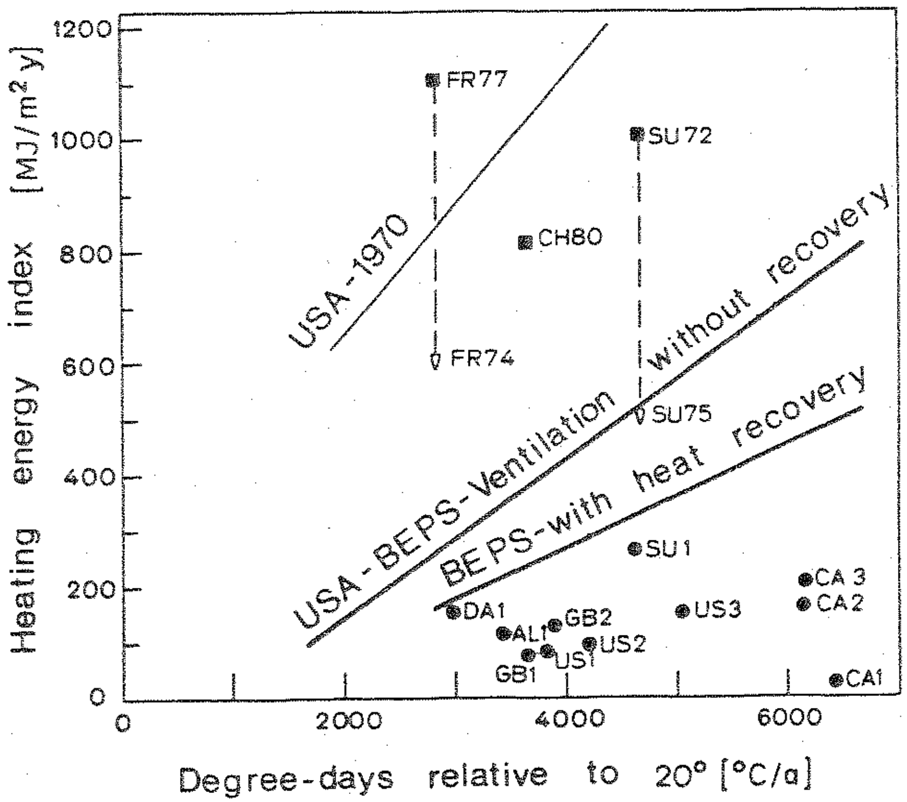

Figure II

Heating energy indices as a function of climate for building stock (■) and pilot houses (●)

This type of statistics also exists for other countries. Correcting the data in order to account for difference in the number of degree-days (40), one has

Country	Year	Equivalent Energy Index
France	1977	1500 MJ/m^2 an
USA	1970	1100 MJ/m^2 an
Switzerland	1979	825 MJ/m^2 an
Sweden	1972	800 MJ/m^2 an

In this table the average number of degree-days in Switzerland was taken as 3650 (relative to 20°C) and the international data have been normalized to that value.

This table shows that the Swiss average (825 MJ/m^2 year) is relatively good in comparison with the international averages.

The international consumption statistics (40) are given in Figure II which shows the energy index as a function of degree-days (relative to 20°). The lines give the average in the USA for 1970, the theoretical results of new building standards for constructions and with normal infiltration at low infiltration with heat recovery. The average in France is FR77, the result (estimated) of the new French standards is FR74. The Swedish average is SU72, the result (estimated) of the new Swedish standard is SU75. The average in Switzerland is CH72. The other points on the Figure correspond to pilot-houses that we described in Chapter I.

TABLE IV

NORMALIZED ENERGY INDICES OF TYPICAL SWISS BUILDINGS AND HIGHLY INSULATED HOUSES

$MJ/m^2 y$	Heating	Hot Water	Electricity	Total
1500 Swiss houses (114)	767	100	108	975
20'000 Swiss apartments (114)	825	80/35	35/80	940
24 houses Scotland (49)	120	124	124	368
5 houses Sweden (60)	215	125	85	425

The energy indices established in Switzerland can also be compared in a more detailed manner with those of diverse highly insulated experimental houses. This is what we have done in Table IV.

2) Typological studies

Another kind of statistical study consists of classifying the building stock into certain types of buildings according to a certain number of criteria: age, energy consumption, thermal improvement possibilities, solar contribution possibilities, etc., with the purpose of being able to precisely predict the eventual effects of a thermal improvement campaign.

A study of this type is being conducted in the canton of Geneva by the Energo group for the Cantonal Commission on Energy and will be completed in the summer of 1981. Similar studies are in progress in other cantons, particularly in the canton Vaud by the Research Institute on the Built Environment (IREC). At the national level, the Battelle Institute at Geneva made a compilation of existing data concerning the distribution of the energy consumption of buildings in Switzerland according to the different types (164).

3) The Energy Budget

A great deal of effort has been made in recent years in the evaluation of the economic attractiveness of energy conservation measures. It is thus that numerous methods have been developed in order to be able to compare between the diverse measures or to optimize the application of one or a set of measures in the case of a given construction or a retrofit.

In the following paragraph, we are presenting in an elementary fashion the main economic methods currently used, without going into the inevitable complications which are introduced when one wants to account for all of the economic factors such as the increase in the energy price, the inflation, the fiscal measures, etc.

In order to place the economic problem in a concrete context, it is interesting to consider the "energy budget" of a household in a typical Swiss residence, defined by the average of the consumption statistics presented in the preceeding paragraph:

Annual "energy budget" of a Swiss residence of 180 m^2 heated by a combination heating-hot water system				
	Energy Index	Annual Consumption	Price of Energy	Annual Expense
Heating	753 MJ/m^2	3227 kg	0.7 Fr/kg	2256.- Fr
Hot water	126 MJ/m^2	540 kg	0.7 Fr/kg	378.- Fr
Electricity	108 MJ/m^2	5400 kW/h	0.12 Fr/kWh	648.- Fr
Car	10ℓ/100km	1500 ℓ	1.2 Fr/ℓ	1800.- Fr

For the sake of comparison, we have included in this table the gas consumption of a car traveling 15'000 km per year.

The figures of this budget correspond only to the purchases of fuels and electricity. It would be necessary, to be complete, to add to these figures the costs of installation, operation and maintenance. However, even in that form the figures show that still today, the expenses for energy only represent a small fraction of the total household budget. That situation changes to some extent if this "energy budget" is compared to the rent. In 1978, meaning before the sharp increase in the oil prices of 1979/1980, the average Swiss

energy budget already represented nearly 20% of the total rent (42). However, in order to decrease the energy consumption in a sensible fashion by energy conservation methods, it is often necessary to invest a relatively considerable sum of money with respect to the expected reduction of the annual "energy budget". Thus, the economic attractiveness of energy conservation measures should be carefully studied, so that the most profitable measures can be applied in order of priority and with success.

4) Economic attractiveness of energy conservation measures

Consider for example a construction project or retrofit for which the total initial investment is I(Fr) and the annual energy consumption Q(MJ/y). The first economic problem consists of establishing criteria which enable the evaluation of the attractiveness of a supplementary investment ΔI(Fr) for the purpose of reducing the annual energy consumption by a quantity ΔQ(MJ/y). One such reduction can be obtained by one or by several combinations of measures which concern, either the active or passive components of the building (measures of a technical nature) or the manner in which energy is utilized in the building (measures of an organizational nature), for example training of heating engineers, installation of monitors for the individual accounting of heating costs, programmed regulation of room temperature, regulations imposing minimal reserves of heating fuels, etc. Certain of these measures can imply use costs for running and maintenance. Finally, for each measure or set of measures, there is the probrem of the manner of financing. This last problem is not simple, particularly because certain conservation measures involve components which have different physical life-times. For example, the physical life-time of the building shell is on the order of 80-100 years, that of the windows is on the order of 30-50 years and that of the oil burner only 10-20 years. This physical life time determines the maximum possible amortization time. However, in economic calculations, one cannot assume times that are longer than the maximum duration of loans granted by banks. It is thus necessary, for each conservation measure, to introduce an economic life-time (which corresponds in general to the duration of the amortization) with respect to which the measure in question should be attractive.

Thus, a calculation of economic attractiveness involves at least six main parameters, in general, specific to a given measure:

ΔI(Fr)	: Total initial supplementary investment
ΔM(Fr/y)	: Annual running and maintenance costs
ΔQ(MJ/y)	: Energy conserved per year
c(Fr/MJ)	: Unit price of energy
n(y)	: Economic life-time
r(%)	: Interest rate

The fundamental criterium on which the majority of the economic attractiveness calculations are based is the idea that in order to be "attractive", the total amount of money saved, equivalent to the energy saved during the economic life-time of the measure in question, should be greater than the total initial investment.

Neglecting to begin with the effect of interest rates, of the increase of energy price or inflation, etc., this criterium can be simply written in the following manner:

$$\Delta I \leq n\ (c\ \Delta Q - \Delta M)$$

Since the quantity between parenthesis is none other than the maximum sum which is available each year to reimburse the initial investment, and n is the number of years considered, this criterium should be absolutely satisfied, whatever the other conditions are, in order to make the measure appear attractive. It is interesting to note, in relation to this very simple criterium, that the effect of rising energy prices, or inflation or financial incentives, can only reinforce the attractiveness. On the contrary, the effect of the interest rate associated with the energy conservation investment, which is either covered by a loan, or is in financial competition with another type of investment, works in the opposite sense. This is obviously due to the fact that the interest payment decreases the sum of money that is available yearly for the amortization of the debt. It is thus indispensible to account for the interest rate, and the usual method consists of reimbursement by constant annuities. This method enables

one to keep the above criterium in the same form, with the condition of replacing n by a discount factor* D(n,r) which is a function of this number of years and the interest rate:

$$\Delta I \leq D(n,r) \cdot (c\ \Delta Q - \Delta M)$$

5) Indicators of economic attractiveness

Based on the criterium of attractiveness that was introduced in the preceeding section, several indicators of attractiveness can also be defined. These indicators are calculated by solving the final relationship of the preceeding section, taken at the attractiveness threshold, with respect to one of the three variables n, r, or c, while keeping the other two fixed (see Appendix III for the details). Each of the three indicators thus obtained have a simple meaning and enable the comparison between several measures from the economic point of view:

a) equivalent energy cost

This indicator is obtained by dividing the total annual cost of the investment (amortization + interest + operating and maintenance costs) by the quantity of conserved energy:

$$c_e = (\Delta I/D + \Delta M)\ /\ \Delta Q \simeq \Delta I/n\ \Delta Q$$

This equivalent cost enables a comparison between the effect of the conservation measure and the price of energy. In particular, this equivalent cost should be less than or equal to the current or future price of energy. This indicator is also the basis for certain simplified methods of optimization for energy conservation measures (44).

In certain cases, it occurs that the inverse of this indicator $1/c_e$ is used instead of c_e. This is then the energy return of the conservation measure (165).

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* $$D(n,r) = \sum_{t=1}^{t=n} (1 + r)^{-t} = \frac{1}{r}\,[1 - (1 + r)^{-n}] \leq n$$

b) payback period

This indicator is simply the minimum time span necessary for the sum total of money saved by the conservation measure considered to be equal to the initial capital invested. To a first approximation:

$$n_r = \Delta I \ / \ (c\ \Delta Q - \Delta M)$$

In practice, for reasonable interest rates and energy price increases, this approximation is found to be relatively good for attractive measures for which the payback period is on the order of 5 years (166).

The major significance of this indicator is that it allows the attractiveness of the conservation measure to be placed in perspective with the economic horizon of the person making the investment. In effect, and this particularly concerns the consumers, that horizon is in general very short, and of a few years at most (166). Under these conditions, the "payback period" is probably the "best" indicator because it indicates the minimum time in which the realized savings can cover the initial investment, and the moment from which the total of these savings constitutes a net benefit for the consumer.

c) internal rate of return

This indicator consists of calculating the interest rate of an investment which would have the same financial return as that provided by the net amount of money equivalent to the annually conserved energy. To a first approximation:

$$r_i = (c\ \Delta Q - \Delta M) \ / \ \Delta I$$

This is often used by economists because it enables an investor to compare the return of invested capital in order to realize one or several conservation measures to the return of another possible investment for the same capital. Another aspect is that the internal rate of return is also directly comparable to rates such as inflation and the increase in energy price. For instance, a first approximation, the inflation rate and the rate of energy price increase can be added to the internal rate of return (167). In this manner for example, one can estimate what the rate of the energy price increase should be in order that a non-attractive measure (r_i less than the market interest rate) becomes attractive.

d) examples of applications

In order to illustrate the practial use of the indicators discussed above, we have compiled their values for a group of possible conservation measures (166) in Table V. By presenting these figures in the form of a table ordered according to one of these indicators, it can be seen that they are not strictly equivalent. Nonetheless, in examinimg this table, as well as similar presentations from other economists (168), the following remarks can be made:

- The most attractive conservation measures are in general those which first concern the organizational measures, followed by those by which the efficiency of the active components is increased, then those which concern the increase in thermal insulation and finally those that use alternative energies.

- The conservation measures are in general more attractive for new buildings than for retrofitted buildings.

- The decrease in the energy consumption of household appliances is in general very attractive.

In order that this type of comparison and classification does not lead to false conclusions, it is necessary to make two important remarks:

1. The calculations above are made with the current costs which are in general decidedly unfavourable for the new techniques. In addition, the indicators are very sensitive to the price of energy and a small increase can completely change the situation.

2. Every energy conservation measure, even when weakly economically attractive, is always interesting from the viewpoint of conserved energy. Such a measure can, and particularly in the case of supplementary wall insulation, lead to a considerable energy saving, when this is integrated over the building physical life-time, even if the initial investment, which is amortized only on a portion of that life time, is not very attractive from a financial viewpoint.

TABLE V

ECONOMIC ATTRACTIVENESS OF SOME ENERGY CONSERVATION MEASURES

	Q (GJ)	ΔQ (%)	ΔQ (GJ)	ΔI (Fr)	ΔI/ΔQ (Fr/GJ)	n	c_e (Fr/GJ)	n_r	r_i	c_e (Fr/t)
Training of heating engineers	14'720	30	4'416	8'150	1.85	3	0.55	0.14	6.90	22
Improved air conditioning control	138	6	8.28	196	23.62	10	2.48	1.6	0.61	104
Replacement of electric motors	51	30	15.18	872	57.45	10	6.73	2.1	0.18	283
Lighting improvement	15'180	12	1'822	57'050	31.32	15	2.66	2.2	0.40	112
Reduction of air infiltrations	207	10	20.70	652	31.50	15	2.48	2.5	0.41	104
Individual cost-accounting for heating	1'656	20	331	12'062	36.42	15	3.19	3.1	0.33	134
Thermostatic valves	943	10	9.66	4'173	432	15	3.89	3.7	0.28	163
Household appliance improvement	3,31	12	0.37	32.60	88.59	10	9.56	4.3	0.09	402
Heat recovery from stale air	16'560	15	2'484	174'410	70.21	15	5.84	6.0	0.17	245
Heating plant replacement	460	25	115	9'128	79.37	15	6.73	7.0	0.14	283
Insulation of a new house	166	33	55.20	7'661	139	30	7.08	13.3	0.08	297
Heat pump	230	58	133	18'745	141	15	10.97	13.7	0.04	461
Double or triple-glazed windows	2'392	15	359	54'605	152	30	7.79	15.1	0.07	327
Insulation of an existing house	129	15	19.32	3'260	169	30	8.67	17.1	0.06	364
District heating	258'980	25	64'745	20.10^6	302	50	11.68	> 25	0.03	491

Real interest rate, r = 3% , current price of energy, c = 12,8 Fr/GJ = 535 Fr/t of heating oil

6) Optimization of energy conservation measures

In the case of a complete building, the problems of the overall optimization of a set of energy conservation measures appears to be a very complex problem. In fact, although the necessary calculations are indeed generally voluminous and involve a large number of parameters, the basic principles are relatively simple. It is first necessary to realize that there are three possible optimization levels.

1. Minimization of total initial cost. This is the traditional method used in the area where the energy price was sufficiently low such that the "energy budget" of tenants remained negligible in relation to the rent. In this case, only the initial costs of construction and installation of heating/ventilation systems are taken into consideration, and the consumption of energy plays a secondary role.

2. Minimization of total annual cost. In this case, one minimizes the total annual cost which is the sum of the amortizement costs and annual interest (corresponding to the active and passive components which contribute to the buildings energy consumption), the eventual operating and maintenance costs and finally the total annual energy consumption cost.

3. Minimum life cycle cost method. For this method the procedure is the same as in the preceeding case with the difference, however, that one adds to the initial investment costs the set of annual use, maintenance, and energy consumption costs totaled over the economic life-time of the building. This method enables the optimization of the building as a system by simultaneously incorporating all the effectively attractive energy conservation measures, and minimizes the overall energy budgets of the tenants.

Let us consider in more detail the two latter methods whose mathematical descriptions are summarized in Appendix III.

a) total annual cost method

In this method, also known as the "annuity method", the assumption is usually that the reimbursement of debts is via constant annuities. In addition, only average annual costs are considered and to a first approximation the possible effects of energy price increase and other economic parameters are ignored. Given this, the total annual cost is written in the form of a sum of terms which are the annuities corresponding to each of the partial investments, the eventual corresponding annual costs of operation and use and the total annual energy expenses. The process of optimization consists then of calculating that sum for each possible configuration (insulation thickness, double or triple windows, heat pump or oil heat, etc) until the minimum is found.

The major interest in this method is that it enables an overall optimization of a building without necessarily having to use a computer program. It is also in general sufficient for the optimization of a not too complicated thermal retrofit, or in any case, of an isolated conservation measure. This method is also advocated, for the simplest situation, by diverse technical handbooks of the Confederation (44,45).

b) minimum life cycle cost method

If one desires a more complete optimization which can eventually account for parameters such as:

- the individual life time of each component;
- the energy price increase (oil, electricity, etc);
- the economic parameter such as inflation, taxes, insurance costs, fiscal incentives, etc;
- etc.

it is then useful to make an economic analysis which minimizes the life cycle cost. With such a method, each term of the sum which constitutes the total cost function to be minimized, is generally affected by a different discount factor of such a nature that the present worth value of each of these terms accounts for all of the above parameters. The calculations are thus laborious and in practice necessitate the use of a computer. In any case, this type of complete calculation most often requires a detailed energy analysis of the building via a computer program, and therefore this necessity is not a real handicap.

For example, the life cycle cost method was used in the United States by the Department of Energy with the program DOE-II, in order to make an economic analysis of their new building energy performance standards (BEPS) (169). Figure III gives a sample result of that study for a private residence located in Chicago. It indicates that with conventional measures, the energy consumption can be lowered by 33%, and that with a decrease in uncontrolled infiltration and the installation of an air-to-air heat exchanger for ventilation, by 58% below the consumption calculated using the 1975 standards. The calculations were made with the American 1978 energy prices and for constant comfort level and a fixed pattern of inhabitant behaviour. In this figure each point represents a given configuration (heating type, glazing type, thickness of insulation, etc). for which the energy index and the life cycle cost divided by the duration of the amortizement have been calculated.

The concept of life cycle cost can also be used in other ways, for instance, in order to compare the economic attractiveness of diverse solutions, such as within the framework of an integration exercise (112), or for household appliances (152).

c) optimization of energy cost

One final remark on the problem of the overall energy optimization of buildings is necessary. In effect one can make an optimization which minimizes either the financial investment (by one of the methods described above) or the energy consumption directly. In the second case, in the limit it is necessary to account for the energy cost of construction. This energy cost accounts for the so-called "grey energy" which is the energy spent for the construction itself, for the manufacture of insulating materials, etc. This grey energy of construction can eventually be greater than that which is conserved at the time of use. A study on this problem is in progress at the EPFL and preliminary results show that the total energy costs of construction (including the heating fuel costs) diminish in a quasi-linear fashion with the heating fuel costs. The energy costs are thus not of decisive significance for the building studied (170).

Life cycle cost and heating energy index calculated for different types of heating systems as a function of the insulation and heat recovery levels for a house located in a 3700 degree-day climate

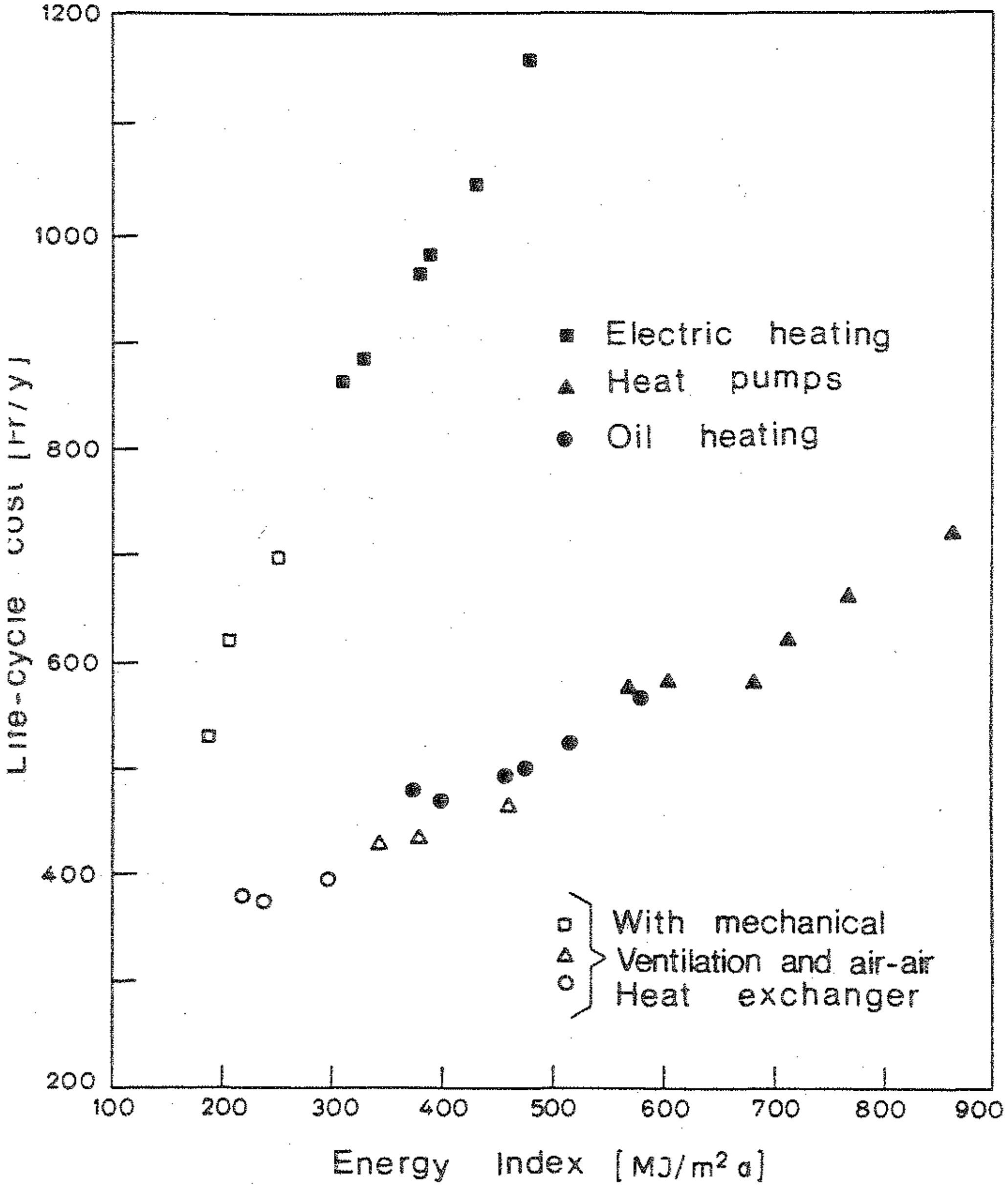

Figure III

7) Overall potential of energy conservation

An important problem with respect to the possible impact of energy conservation measures is that of their overall effect on the energy consumption of an entire country. In Switzerland, within the framework of the Global Energy Conception (GEK), the Confederation financed a study on this problem as well as on the influence of fiscal and legal measures (171). Concerning this second aspect, another study is financed by the National Foundation of Scientific Research (36).

A dissertation, presented at the end of 1979 by an economist of the Graduate School of Commercial Studies at St Gall, showed that if all the possible energy conservation measures were implemented, the level of Swiss energy consumption in year 2000 could be at the same level as that of 1975 (172). Similar conclusions have been obtained for other countries and in particular for England (173).

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CHAPTER VI

A BRIEF SYNTHESIS AND RECOMMENDATIONS

After having written a review of the current research in the area of energy conservation, one is naturally inclined toward certain general reflections concerning the results, and the importance and directions of future research. An important consideration is that there are numerous examples of pilot projects where the energy consumption for heating is on the order of 100 MJ/m^2 year, whereas the Swiss average is 750 MJ/m^2 year. These low energy houses take advantage of: very substantial insulation (10 to 30 cm of insulation, $k \approx 0.1 - 0.3\ W/m^2\ {}^oK$), an architecture and orientation that optimize the passive solar contribution, a maximal reduction of uncontrolled air infiltration, and most often a mechanical ventilation system with heat recovery. Thus the technical feasibility of constructing new, low energy houses has been amply demonstrated.

Considering that the large of majority of the current housing stock will still exist in the year 2000, it is evident that the problem of the thermal renovation of these structures is of greatest priority. A significant number of experiments have indicated that energy savings of 50% are not rare and it is possible to reduce consumption to about 250 MJ/m^2 year. As in the case of new low energy building construction, the most important aspect is the quality of the work on both conceptual and practical levels. Certain projects have been quite successful but there are also instances where there has been no significant improvement. It appears that these latter cases can be attributed to having either ignored the improvement, often relatively cheap, of the heating plant efficiency, or having placed an emphasis on improving the insulation without considering air infiltrations which are still very difficult to reliably measure with our present knowledge. The greatest energy saving possibilities for buildings of relatively recent construction lie in reducing the losses due to air exchange (uncontrolled infiltrations and ventilation) and down-sizing the heating plants. In such cases this can usually be done without necessarily replacing the oversized boiler. For older buildings, the fitting of as much external insulation as possible when the building shell is renovated should also be accompanied by a corresponding adjustment to the heating plant.

The majority of experiments, made with new buildings or thermal retrofit, concern individual houses. Otherwise, there have been only a few experiments made with large apartment buildings. It is already known that theoretically they could consume about 50% less per m^2 than houses. Upon viewing the statistics, however the measured energy index of apartments is very nearly identical to that of houses. This contradiction demonstrates the ample amount of work to be done in this area.

In the area of household appliances and lighting, the studies indicate that equally spectacular savings are possible and are on the order of a factor of five or more. The new, low energy consuming products can represent a very important market for the future, and certain companies, notably Japanese, are preparing new equipment of low electrical consumption in order to effect considerable reduction of energy use in the household and commercial sector.

An essential aspect of these new technologies is obviously their economical attractiveness. At the current price of energy this has already been demonstrated for a number of them. One of the most significant points stressed, however, at the first conference of the IEA on the "New Energy Conservation Technologies and their Commercialization" in Berlin (April 6-10, 1981), was that the introduction of intrinsically profitable measures in the residential sector is remarkably slow in comparison with the industrial sector where the possibilities for economizing are often relatively smaller. The current trend toward the application of energy conservation measures in the residential sector is such that it will take from 15 to 20 years to generalize the use of techniques that are currently already profitable. This paradoxical situation is due to, among other things, the complexity of the market in this sector and to the contradicting interests of actors: constructors, owners, tenants, producers, energy retailers, etc. Another important paradox that became apparent at the Berlin Conference is the fact that, with the exception of Japan, throughout most of the industrialized world the annual energy consumption for heating is equivalent to approximately 4000 liters of oil per dwelling, and that this is independent

of climate. The implication is that the most important and most profitable energy savings are still to be realized in the most temperate areas of these regions while most of the current efforts are being made in the coldest regions where houses are often already well insulated. In the conclusion of a recent study of the Commission of European Communities (183) it was most aptly stated that the residential sector is where "the savings are at the same time the most promising and the most uncertain". They are promising because the calculations and the pilot studies show unambigously that energy consumption can be decreased by a factor of two or more. They are uncertain because of the broad diversity of obstacles (variations in local conditions, insufficiently informed engineers, non-existence of adequately trained personel to complete the work, tennant-landlord conflicts, too few opportunities to obtain low interest loans for thermal improvements, etc).

What are some possible research goals for the coming years? Intending to be neither exhaustive nor peremptory, a number of ideas can be suggested. Despite an abundance of technical information, we still know very little about the social feasibility of energy saving measures. At the macro-economic level of large groups of buildings, particularly of regions or countries, it is therefore necessary to confront the socio-political problems posed by thermal renovation and study the different measures which will encourage this type of renovation on a large scale. The research in this domain should lead to the elaboration of concepts and detailed strategies, with equal emphasis on both the technology of thermal renovation and its application on a global scale to a region or country. Today there are numerous instances of thermal retrofitting. It would be of prime interest to obtain as much statistical information on those initiatives as possible and to discover the motivations, what has been successful, the cost and the techniques employed. It would be equally useful when teams of experts could make detailed analyses of the cases where the results have been especially good but also insignificant or nul.

This statistical information would be easier to obtain if, in collaboration with the professional associations, one could define what minimal technical data should be taken at the time of renovation. A renovated building should provide such data as specific consumption (before and after the renovation if possible), general characteristics of the building, number of degree-days and added cost. In fact, it is unfortunately often very difficult to obtain this information. These statistical studies would permit a better understanding of the disparity between what can be expected if everything is done very well and what is achieved in practice by engineers or architects who do not necessarily have an extensive training in these areas. This is the fundamental problem of all energy savings campaigns and merits studying in the context of a national plan. These statistical studies should be completed and refined by typological studies which would permit the classification of "renovation-types" depending upon the age of the building, its geographical location, construction characteristics, purpose, occupation patterns, etc. These typological studies should be made separately for the building shell and heating systems. Thus, as it has been previously stressed in the text, very little is known about the extent to which building renovations are economically profitable. Micro-economic studies on this theme sould be extremely useful.

Statistical studies and data banks are equally necessary for household appliances. These studies would be essential in order to implement energy labeling regulations and consumption performance, standards and to inform the consumer.

The development and deployment of simple methods for the energy audit (direct measurements of energy performance of the house and calculation via portable calculators) is an absolute priority. With these diagnostics one should be able to not only calculate the details of the renovation and its effects on energy use, but also dilineate the renovations in order of decreasing profitability. In effect, it is necessary that official agencies, constructors and future clients have at their disposal date about the twenty or thirty year's cost of a given construction ("life-cycle cost") as well as data on the economic profitability of thermal improvements. Since technical and economic conditions can vary among regions and among types of buildings in the same region, it does not suffice to limit the studies to a very small number of pilot renovations. It is necessary to find a way of encouraging a large number of diverse retrofit pilot studies. This is not to say that it is necessary to finance all of those renovations, nor to instrument them in all and every fashion. What is necessary, however, is to make financial support available for the performance monitoring and for the critical analysis

of results which should be scientifically credible in order to provide valuable information. The cantons could have an important role to play in this context. The priority of these pilot-experiments should be the large apartment buildings since they constitute a considerable portion of the building stock and have been the object of only a very few experiments of that kind. Given that Switzerland possesses a high proportion of these buildings, it would be natural that it plays a leading role in this domain. The work has nevertheless begun with the experiments on Limmatstrasse and in La Sallaz, but more could and should be initiated. It would also be appropriate to do an experiment on a large new low energy consuming apartment building (less than 100 MJ/m^2 year for heating). That experiment would be, to our knowledge, the first in the world.

It is necessary to stress the importance of developing fundamental studies on the physics of buildings. Ultimately at the bases of all issues there is the comprehension of fundamental problems or the necessity to integrate the results of foreign research, and only high level research teams can maintain an adequate level of knowledge.

The consumption of energy for heating depends to a large extent on the rate of air renewal. In a standard building that part corresponds to 20-30% of the total. In a low energy consumption building, however, when the level of insulation is increasing, the fraction of energy used to reheat fresh air increases rapidly above 50%. In order to be able to continue to reduce the energy consumption for heating, it is thus necessary to devote particular attention to a range of fundamental problems concerning the rate or air renewal. It is necessary to be able to determine with precision the air change rate in a given building and to normalize the instrumentation and methods so that comparisons can be made between different countries.

In the domains of renewal of air and quality of air, the following tendencies can be identified:

- construction of buildings with reduced uncontrolled air infiltrations;
- mechanical ventilation with flow control as a function of needs and heat recovery;
- air quality monitoring;
- accounting for the number of occupants;
- improvement of ventilation for the elimination of pollutants and tobacco smoke;

- creation of zones reserved for smokers;
- development of new air cleaning apparatus;
- control and elimination of pollution sources;
- improvement of air distribution systems.

For our country the priority is the study of ventilation systems with heat recovery for large apartment buildings (centralized or decentralized systems (one heat recovery unit per apartment)).

Referring again to the building components it would be of interest to develop a research on the insulating materials particularly adapted to Swiss conditions.

Windows also represent an important subject of research. The problems posed in constructing superinsulated windows are numerous:

- achieving selective surfaces of low emissivity;
- maintaining a good vacuum ($<10^{-4}$ mm Hg) for a number of years;
- development of window frames having thermal characteristics comparable to those of the window;
- costs of fabrication.

Heating systems should also be one of the research themes. Studies on efficiencies should be pursued as well as on optimal combinations of bivalent or multivalent systems with respect to energy and economics. The low energy houses of the future will require very low power heating systems. Research is necessary in order to identify these very low power optimal systems. It is noteworthy that the results of research on low energy housing has had only a minimal impact on the other aspects of the energy problems. Thus it appears more and more that electrical resistance heating (as opposed to electric heating by accumulation) adapts well to very low consumptions because of its facility of regulation and its ability to quickly attain a given temperature (these remarks are naturally only valid if this type of heating is subject to construction standards more severe than those of today or, even better, to consumption standards). In comparison, according to numerous experts, district heating does not appear to be profitable under these conditions, as is the case with active solar systems (for space heating). This shows the necessity of research on systems able to provide heat when the specific consumption attains its optimal value.

More explicitly the problems can be stated as follows:

a) What is the optimum combination of substitution and energy saving measures which insure a maximum conservation of energy? For example: should one construct solar houses, use heat pumps, or simply superinsulate the buildings and use advanced oil heating systems or electrical heating?

b) What is the "best" heating system for a building in a given region? Should one use central heating or district heating? What forms of energy should be chosen? What is the best combination when binary systems are required, i.e., solar/oil , heatpump/electric... ?

c) What is the "best" heating system for a room or an apartment in a given building: i.e., central heating, by individual rooms, by radiators or convectors, at low or high temperature, in the floor or in the ceiling, by heaters or with hot air...

All of these problems are not well studied and there is a need for theoretical and experimental research. This complex of problems lends itself quite naturally to the question of regional and urban integration of energy systems. The consumption of energy will require a change in certain aspects of urbanism such as the distribution and recovery of the heat from water, transportation and zoning. The following areas of research are particularly worth mentioning:

- consideration of energy needs and waste of different industries with respect to their relative locations;
- consideration of the industrial waste energy for the other needs of the urban community;
- integration of materials recycling within the urban organizational structure;
- study of optimal systems of heat distribution and recovery (reserve of low temperature heat for heat pumps, ideal sizing of district heating, etc);
- study of integrated electricity and heat, cogeneration systems in the urban setting. (What is the ideal size of a cogeneration plant given the urban and ecological constraints?);
- integration of renewable energies in the urban energy distribution network (should solar, biogas, geothermal and heat pumps be connected into the distribution system of neighborhoods, zones, cities? At what temperature?

A certain amount of research should be co-jointly undertaken by economists, technicians and jurists on the subjects of heating cost accounting and building codes. Note in this regard that the requirements of the existing Swiss standards are still rather modest relative to Swedish building codes which the specialists are considering as excellent. The ideas contained in the American BEPS, based on consumption standards, should be the subject of a thorough legal and technical assessment. From the perspective of heating cost accounting technique, the development of systems of measure and control is required and this will probably be done by private industry.

There remains to mention one last general theme of research concerning the impact of the politics of energy conservation on the economic evolution of the country and the security of supply. In particular the impact on employment, growth, security with respect to international crises (a very important aspect stressed by many recent high level studies (184, 185)), the political and social stability etc. A new national research program partially addresses itself to these questions and this is to be congratulated. To conclude, we quote a recent report of the Commission of European Communities (183):

"It appears in effect - and this is our first major conclusion - that the gravity of the risk taken by Europe due to the fact of its dependence with regard to the exterior requires a vigorous and comprehensive policy of rationalization in the use of energy. The lack of progress made in this direction over the last five years makes this recommendation even more crucial.

However, the results of studies on the technical possibilities of decreasing energy consumptions indicate that the potential improvement is considerable, evidenced by gains of 15% to 50% of consumption with the current state-of-the-art. It is thus not in vain that one should exploit this veritable resource. This is our second major conclusion.

The third conclusion concerns economic growth. Europe has an imperative need that its growth should be sustained - at the progression rate on the order of 4% per year - at least until 1990, in order to create sufficient employment and adapt its industry to the new conditions of international commercial competition. But it is not possible to satisfy this requirement - to assure a sane, sufficient and continuous growth - unless at the same time, one truly finds the means to minimize the consumption of energy".

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APPENDIX I

PROGRAM OF THE INTERNATIONAL ENERGY AGENCY OF RESEARCH AND DEVELOPMENT ON ENERGY CONSERVATION IN BUILDINGS AND COMMUNITY SYSTEMS

In its implementing agreement, the International Energy Agency defined the series of projects *(Annexes)* presented below with the description of their constituent substasks.

PROJECT I (completed)

EVALUATION OF MEASUREMENT METHODS OF ENERGY NEEDS IN BUILDINGS

Objective	To provide for surveying, collecting and evaluating analytical methods used for predicting loads and energy consumption for buildings.
Subtasks	I.1. Compile existing analytical methods; I.2. Determine the consistency of results obtained by these methods; I.3. Exchange of results and access of the participants to the DOE-II computer programm of Berkeley.
Participants	Belgium, Canada, England, Italy, Switzerland, USA.
Swiss contribution	This project has led to the installation and use of the program DOE-II at EMPA.

PROJECT II (completed)

METHODS FOR THE ENERGY PLANNING OF COMMUNITY SYSTEMS

Switzerland did not participate in this project. Project VI is the continuation of Project II.

PROJECT III

EVALUATION OF ENERGY CONSERVATION MEASURES FOR THE HEATING OF RESIDENTIAL BUILDINGS

Objective — To solve the problem of generalizing experimental results from different times and places on the national level, and provide the participants with generalized information on the energy savings potential of different energy conservation measures.

Subtasks — III.A. Calculation methods to predict energy savings in residential buildings.
- i) Calculation methods in general;
- ii) Influence of occupants;
- iii) Recommendation of calculation methods;

III.B. Handbook of guiding principles concerning the design of experiments, instrumentation and measuring techniques.

III.C. Evaluation of national case studies and generalization to other countries.

Participants — III.A. Denmark, Holland, Italy, Sweden, Switzerland, USA.

III.B. Belgium, Holland, Italy, Sweden, Switzerland, USA.

III.C. Belgium, Denmark, Sweden, USA.

Swiss contribution — III.A. The instrumentation of an apartment building by the EPFL at Lausanne and a house at Maugwil (SG). The measurements taken in these buildings could be compared with the predictions of DOE-II. This program, as well as JAENV of the EMPA was used to analyse a house at Vetlanda in Sweden and a fictitious building "Teknikern".

III.B. The writing by EPFL and EMPA of a chapter for the handbook on the design of experiments, instrumentation and measuring techniques.

Other activities in progress or proposed within the framework of Project III — III.A.ii. Sweden is conducting a study on inhabitant behavior and will present a pilot-study based on a test-building.

Belgium, Denmark and Italy are preparing an inventory of test houses and new measurements.

III.B. Italy is collecting and compiling the participant contributions to the handbook.

III.C. On the initiative of the USA, a seminar on the thermal retrofit of windows was held at Delft in Holland on the 9th and 10th of June 1980. An additional seminar on the "energy audit" and the "house doctor" concepts for thermal retrofit was held from the 13th to the 15th of April 1981 at Elsinore in Denmark.

Denmark is preparing a contribution on the supplementary insulation of walls and the USA is studying that of roofs.

Sweden is studying heat recovery in ventilation systems and individual room temperature control equipment.

Switzerland plans to present some of its pilot-retrofits: the improvement of "Limmatstrasse" in Zurich, the "Solar House" of Zug, and a selection of federally owned buildings.

A substask III.D is in preparation. Its objective will be to study the overall thermal balance of windows.

PROJECT IV

GLASGOW COMMERCIAL BUILDING MONITORING PROJECT

Objective — To measure in detail the energy inputs, flows and outputs, and internal/external environment of a commercial office building, and use this data to make in depth comparisons of the actual energy performance with that predicted by load/energy computer programs.

Subtasks
IV.1. Instrumentation;
IV.2. Data recording analysis;
IV.3. Calculation of building performances;
IV.4. Preparation of building specifications and weather tapes;
IV.5. Assistance to computer analysts;
IV.6. Documentation of results;
IV.7. Periodic meetings.

Participants — Belgium, Canada, England, Switzerland, USA.

Swiss contribution — The energy behavior of the building will be simulated with DOE-II at EMPA and compared with the measured data provided by the University of Glasgow to the participants.

PROJECT V

ESTABLISHMENT OF AN AIR INFILTRATION CENTER (AIC)

Objective — To support institutions active in air infiltration research through the collation analysis, evaluation, and dissemination of experimental data and technical information, and to assist in the coordination of national research activities in air infiltration.

Project V
(continued)

Participants — Canada, Denmark, England, Italy, Holland, Sweden, Switzerland, USA.

Air Infiltration Handbook — The center will assist the Swedish participant in the production of a handbook developing a set of guiding principles for reducing air infiltration in new and existing residentials and commercial buildings and including instrumentation and methods for infiltration testing.

Swiss contribution
1) EMPA is diffusing the information of the AIC.
2) The writing of a chapter on the Swiss air renewal standards for the air infiltration handbook.
3) The translation into German of English technical terms for an air infiltration glossary (airgloss).

PROJECT VI

ENERGY SYSTEMS AND DESIGN OF COMMUNITIES

Objective — To establish planning procedures and general analytical methods for energy conservation in urban communities.

Participants — FRG, Greece, Italy, USA.
Switzerland is not participating in this project.

PROJECT VII

LOCAL ENERGY PLANNING

Objective — To analyze the dependence of energy conservation projects on local governments for their implementation.

Subtasks
- VII.1. Consumer preferences and needs;
- VII.2. Building codes and loan grant programs;
- VII.3. Role of local governments and local planning in meeting short term and long term energy problems;
- VII.4. Economic environmental, technical and institutional issues associated with the development and operation of energy supply systems for different energy supply scenarios;
- VII.5. The energy saving potential in the use of underground space.

Participants — FRG, Sweden, USA.
Switzerland announced that it would not participate in this project.

PROJECT VIII

INHABITANT BEHAVIOR WITH REGARD TO VENTILATION

Objectives — See the substasks.

Subtasks
- VIII.1. To determine the actual behavior of inhabitants regarding ventilation and to correlate it to outdoor and indoor climate;
- VIII.2. To estimate the amount of energy that is lost due to this behavior;
- VIII.3. To study the corresponding motivations;

Project VIII (continued)

- VIII.4. To study whether such behavior can be modified by educational programs and to estimate the amount of energy saving which might result therefore.

Interested countries — Belgium, FRG, Holland, Switzerland

Preliminary Swiss contribution — In 1981 Switzerland will begin a pilot-study in order to verify the "feasibility" of such a project.

PROJECT IX

MINIMUM VENTILATION RATES

Objective — To collect experimental data and establish objective criteria with regard to standards on the minimum ventilation rate in buildings.

Participants — Belgium, Canada, England, FRG, Holland, Italy, Switzerland, USA.

Swiss contribution — At present the EPFZ is conducting a bibliographical research in order to define the state-of-the-art and research needs in this area.

PROJECT X (proposed)

SIMULATION OF SYSTEMS

Objectives	X.1. Improve methods of building systems simulation; X.2. Provide some reference examples of global analysis in residential and communial buildings; X.3. Provide realistic assumptions on lighting scenarios, occupancy behavior, office material use, i.e., on internal loads, which can have an impact on the system simulation; X.4. To establish some standardized description of all the building equipment, i.e., its lighting devices, appliances, and its hot water and space H.V.A.C. equipment including all of the "auxiliaries" (fans, pumps, etc).
Interested countries	Belgium.

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APPENDIX II

ELEMENTS OF THE THERMAL BEHAVIOR OF BUILDINGS

This appendix describes two simplified models which allow for the calculation of the approximate energy consumption of buildings. The presentation of these two models provide the opportunity to introduce and define the most essential of the technical concepts that are used in the present report. Also included are some considerations on energy indices of buildings and the seasonal efficiency of oil heating plants.

1) Transmission and air renewal losses

The two principal sources of a building's energy loss are the transmission of heat through the walls, windows, doors, which constitute the boundaries of the building envelope, and air renewall losses determined by uncontrolled infiltrations and the ventilation system. These losses can be characterized by the two average parameters $\bar{k}$ and $\bar{n}$. The annual energy consumption can be expressed in first approximation as a function of these variables in the following manner (7):

$$Q = 0.0864\ (A\bar{k} + V\bar{n}\ 0.34)\ D\ \frac{1}{\eta}\ (1 - \tau) \qquad [1]$$

Q : The total annual end use energy supplied to the heating plant [MJ/y] ;

A : The outside surface area of the heated building shell [m^2] ;

V : The heated volume of the building [m^3] ;

$\bar{k}$: The average heat transmission coefficient (per unit surface area and unit temperature difference) of the building shell elements [W/m^2K]

$$\bar{k} = \frac{1}{A} \Sigma k_i \qquad A = \Sigma A_i$$

$\bar{n}$: The air change rate expressed as the "number of air changes per hour" [h^{-1}]

D : The number of degree-days, meaning the sum of the positive differences $\bar{T}_{int} - \bar{T}_{ext}$ between the average inside and outside temperatures for the duration of the given heating season. In Switzerland the number of degree days is calculated for $\bar{T}_{int} = 20^oC$ and the heating season is defined by $T_{ext} < 12^oC$:

$$D = \sum_{jours} \left(20 - \bar{T}_{ext} \Big|_{< 12^o} \right) \Big|_{> 0}$$

The Swiss average, weighted by the building stock volume is 3654 degree-days per year;

η : The overall seasonal efficiency of the heating system. For a standard oil-fired central heating plant the average value of η is on the order of 0.5 to 0.6;

τ : The correction term which aggregates the supplementary energy gains contributed by the sun, people, electrical appliances, etc.

Dividing [1] by the building's heated surface area yields its energy index:

$$J = 0.0864\ h\ (f\ \bar{k} + 0.34\ \bar{n})\ D \frac{1}{\eta} (1 - \tau) \qquad [2]$$

$J = \frac{Q}{S}$: Energy index [MJ/m^2y];

S : The heated floor surface area of the building [m^2];

$h = \frac{V}{S}$: The average ceiling height of the heated volume [m];

$f = \frac{A}{V}$: The building form factor [m^{-1}].

The form factor of various structures ranges between 0.8 for small houses and 0.4 for large buildings. This parameter plays an essential role in the determination of the maximum average admissible coefficient $\bar{k}$ according to the regulations of the Swiss Society of Engineers and Architechts (32).

In a study conducted by EMPA for the Federal Office of Environmental Protection (7), the parameter τ has been theoretically evaluated for a series of typical buildings constructed alons the lines of traditional architecture and with different degrees of insulation. A good correlation between this parameter and the product $f \cdot \bar{k}$ has been noted.

With the help of the above formulas, it is easy to calculate the approximate energy index of both a small house and a large building constructed in accordance with current regulations:

	House	Large apartment building
f	0.8	0.4
$\bar{k}$	0.6	0.75
J	800 MJ/m^2	580 MJ/m^2

The following parameters were used for this calculation:

$$h = 2.6\ ,\ \bar{n} = 0.5\ ,\ \eta = 0.5\ ,\ \tau = 0.25\ ,\ D = 3654.$$

2) Building energy balance

For the comprehensive study of building energy behavior, it is possible to construct particularly simple models. Such models are useful to compare the performances of different buildings, with respect to their respective energy consumption, to calculate the variation of their consumption from one year to another, or to quantify the gains due to a thermal retrofit. On the other hand, such models cannot be used to calculate and optimize with the necessary presision the construction of new buildings and especially those that are complex (with ventilation, climate control systems, etc).

In a building where the inside temperature is kept constant by a thermostat, the energy balance can be written in the following form (174):

$$\eta Q = (B + N + H \cdot D) - (E + P + F \cdot \phi) \qquad [3]$$

This relationship is exact under stationary conditions and expresses the quantity of energy Q supplied to the heating system (during a given heating period) as the difference between the building losses (towards the ground, the neighboring buildings and the atmosphere) and the supplementary gains (contributions from electrical home appliances, people and the sun):

Q : The total end use energy supplied to the heating system during the given heating period [MJ/y];

η : The total efficiency of the heating system. This parameter accounts not only for the efficacy of the plant itself, but also for the different recovery and loss factors characteristic of the particular structure;

B : The energy loss to the ground, assumed constant;

N : The energy loss (constant in principle) to adjacent structures when the given dwelling has common bondaries with other dwellings. In the case of an apartment situated in the middle of a building this parameter can be more important than B, and may even constitute a gain;

H·D : The energy loss to the atmosphere by thermal conduction (through the walls, the windows, etc) and by air exchanges due to infiltrations and ventilation. This loss is expressed by the product of a constant H (measured in Joules/^{O}K day), a building characteristic, and the number of "degree-days" corresponding to the given heating period;

E : The energy contribution of electric household appliances, lighting, and other service appliances used in the building;

P : The metabolic energy contribution of the inhabitants (about 100 W per person);

F·ϕ : The energy contribution of the sun, mainly through the south facing windows. Since ϕ is the total solar energy flux (expressed in J/m^2) during the heating period, F represents an area characteristic of the building equivalent to an ideal glazed surface which captures the total solar energy which is stored passively by the building.

The determination of the characteristic thermal parameters of a building η, B, F and H (for example by measurement of the analysis of heat and electricity bills) allows for the calculation of the building's energy consumption Q as a function of the meteorological variables (the number of degree-days D and the total solar flux ϕ) and the additional occupancy factors described by N, E and P.

3) Energy index and energy signature of buildings

The energy index is the annual energy consumption per unit of heated floor area and is usually expressed in MJ/m^{2}y. This index is in fact a measure of the average dissipated power and can thus be expressed in W/m^2. Therefore:

$$1000\ \text{MJ/m}^2\text{y} = 31.71\ \text{W/m}^2$$

Expressed in W/m^2 the energy consumption index can be directly compared to the installed power of the heating plant per m^2.

The major inconvenience of the energy consumption index is that it mixes the building's thermal characteristics with the energy consumption behavior patterns of the inhabitants, such as the preparation of warm water, the inside temperature etc. A more refined concept which allows for a more precise determination of the building thermal characteristics, and which is independent of climate is that of the energy signature.

A building's energy signature is the rate of change of its energy consumption with respect to outside temperature per unit of heated volume (182):

$$\sigma = -\frac{1}{V}\frac{\Delta Q}{\Delta T_{ext}} \qquad [4]$$

From [1] and [3], Q is, to a good approximation, a linear function in T_{ext} and the following proportionalities are thus valid:

$$\sigma \sim G = \frac{A}{V}\bar{k} + 0.34\ \bar{n} \qquad [5]$$

$$\sigma \sim H/\eta \qquad [6]$$

The total energy index calculated as a function of climate for different types of inhabited buildings

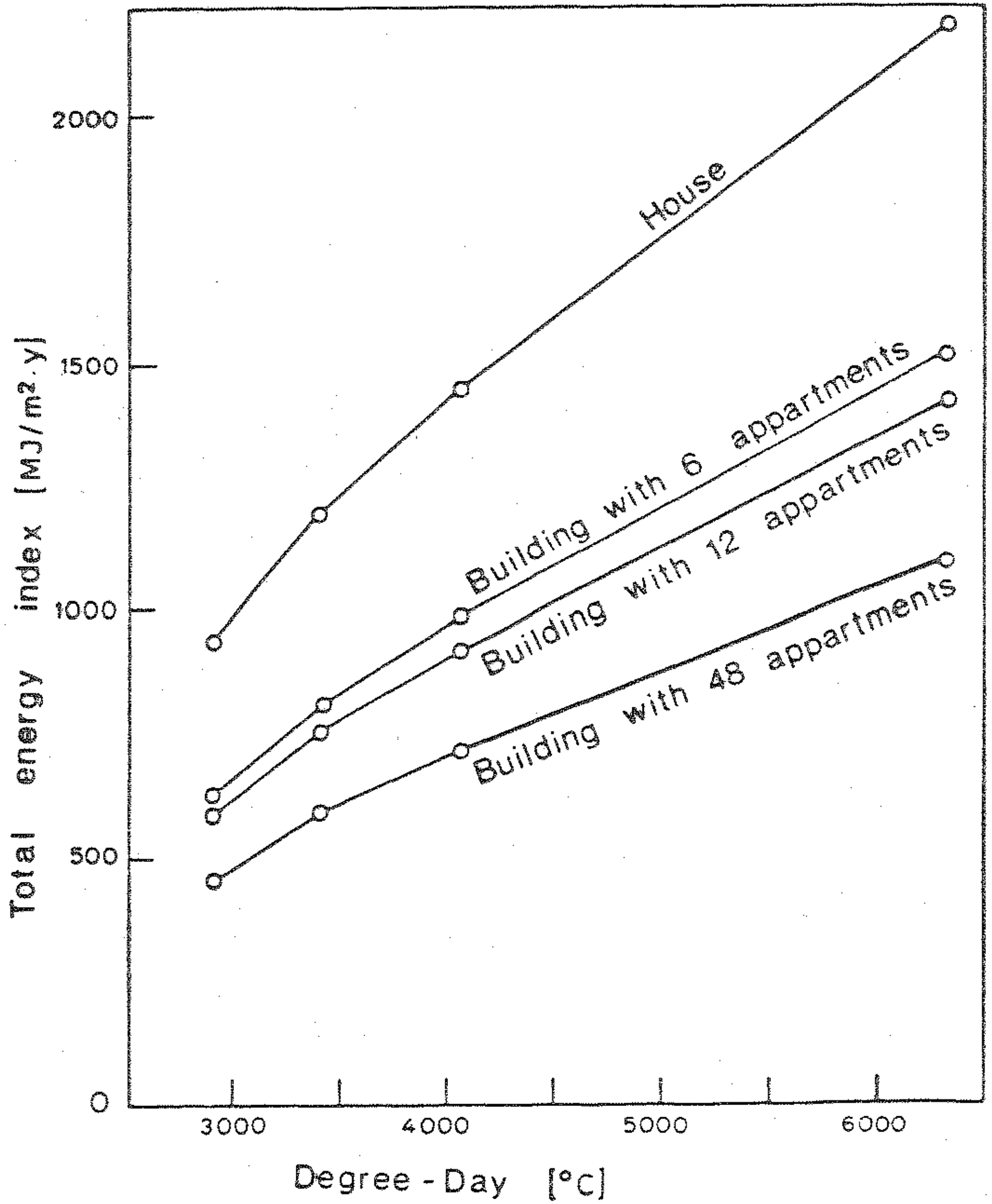

Figure IV

The annual oil consumption calculated as a function of inside temperature

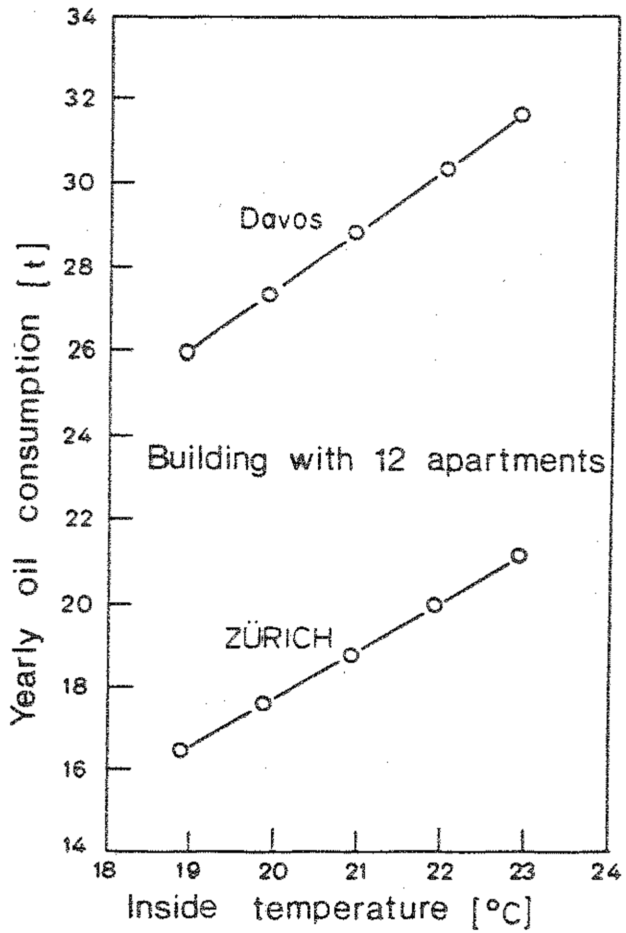

Figure V

The weekly oil consumption for an apartment building measured as a function of average outside temperature, and the determination of its energy signature

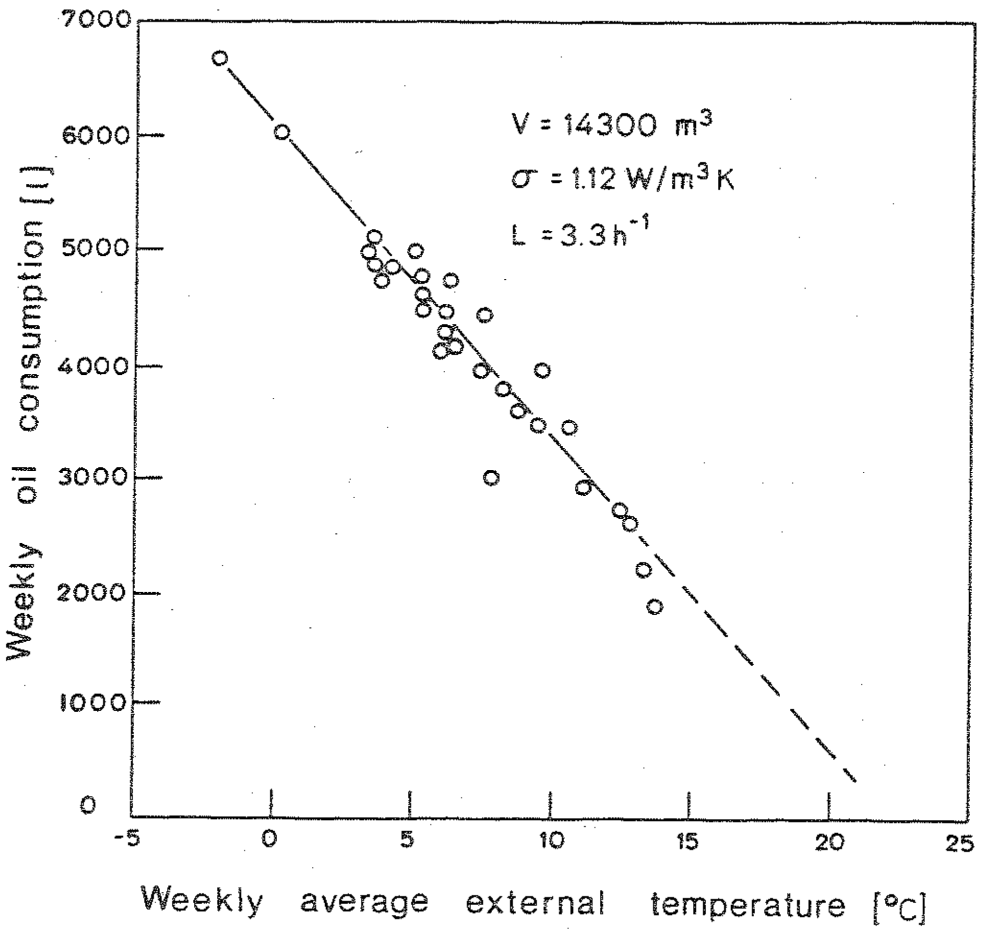

Figure VI

A simple method for determining the energy signature of a building is to record its weekly energy consumption and then plot it as a function of the average weekly outside temperature, as is shown in Figure VI. It is useful to express the signature in units of air changes per hour (46) because this allows, at least in principle, a direct comparison with the hourly air change rate. For this purpose σ is divided by the heat capacity of air, $C_{air} = 0.34\ Wh/m^3K$:

$$L = \sigma / C_{air} \qquad [7]$$

In the case of the building of Figure IV, the energy signature is $1.12\ W/m^3K$, the equivalent of 3.3 air changes per hour (46).

4) Overall efficiency of heating systems

The overall efficiency of a heating system depends upon a large number of parameters which are not always easy to measure, and the definitions of these parameters differ considerably among the various authors. A symposium on this subject will occur in september 1981 at Delft in Holland (175) and the organizers are proposing the use of the following definitions in order to facilitate comparisons between the results which will be presented.

Let Q represent the net energy that is used to maintain a given heated room at a constant temperature. The overall efficiency can be resolved into 4 or 5 factors which each correspond to a different type of energy loss. Therefore:

$$\eta = \frac{Q}{Q + P_A + P_B + P_C + P_D + P_E} = \eta_A\ \eta_B\ \eta_C\ \eta_D\ \eta_E \qquad [8]$$

Going from the heated room to the boiler via the distribution system, one has the following losses:

P_E : Losses at the emission by the radiators;

P_C : Control system losses (the heat is not always delivered at the right moment);

P_D : Distribution system losses (the heat is not always delivered at the right places);

P_B : Heating plant losses due to boiler inefficiencies;

P_A : Auxiliary losses (electricity consumed by pumps, ventilators, the burner, controls, etc).

The partial efficiencies are written as:

$$\eta_E \quad : \quad Q/(Q + P_E) \qquad [9]$$

$$\eta_C \quad : \quad (Q + P_E)/(Q + P_E + P_C) \qquad [10]$$

$$\eta_D \quad : \quad (Q + P_E + P_C)/(Q + P_E + P_C + P_D) \qquad [11]$$

$$\eta_B \quad : \quad (Q + P_E + P_C + P_D)/(Q + P_E + P_C + P_D + P_B) \qquad [12]$$

$$\eta_A \quad : \quad (Q + P_E + P_C + P_D + P_B)/(Q + P_E + P_C + P_D + P_B + P_A) \qquad [13]$$

In gas or oil fired central heating plants, the auxiliary losses are often combined with those of the boiler in the following manner:

$$P_{AB} = P_B + P_A \qquad \eta_{AB} = \eta_A \ \eta_B \qquad [14]$$

It is interesting to note that the resolution of the total efficiency into 4 or 5 factors is generally possible for heating systems regardless of whether the burner is in a house or at a central plant.

5) Seasonal efficiency of a boiler

When the annual energy consumption of a building is calculated using formula [1], the overall seasonal efficiency η is composed of the product [8] of the average seasonal values of the partial efficiencies. In the case of central heating, the most important one is the boiler seasonal efficience η_B. This efficiency depends upon the sizing of the boiler which is expressed

by the load factor α of the plant. The load factor is defined as:

$$\alpha = t_b/t_o \qquad [15]$$

where t_o : The time duration in which the boiler is maintained at constant temperature, i.e. the heating season duration;

t_b : The total time that the burner actually functions.

In practice, the correct power sizing of the boiler with respect to the heat consumption of the building corresponds to a load factor of α = 0.3 to 0.4.

The boiler temperature, in general, is maintained at constant value even when the water circulation pump is stopped. The time t_b can be resolved into two periods:

$$t_b = t_u + t_p \qquad [16]$$

t_u : the time in which the burner furnished heat to the heating systems (the useful working hours);

t_p : the time in which the burner functioned to maintain the boiler at constant temperature without supplying useful heat to the system.

Thus, the so-called stop-factor due to the maintenance of constant temperature is:

$$q = (t_p \ / \ t_o - t_u) \qquad [17]$$

where $t_o - t_u$ is nothing but the time in which the boiler has not supplied useful heat to the system. This stop-loss factor is a constant that is characteristic of the boiler and which is determined by measuring the fraction of the time when the burner should function to maintain the boiler temperature constant when the water circulation is stopped.

The boiler seasonal efficiency can then be written as the product of two terms:

$$\eta_B = \eta_x \ \eta_p \qquad [18]$$

where η_p : The actual boiler efficiency at full charge;

η_x : The boiler use efficiency that takes account of the intermittent functioning of the boiler.

According to our definitions:

$$\eta_x = t_u / t_b \qquad [19]$$

which can also be expressed in terms of the load factor and the stop factor:

$$\eta_x = \frac{\alpha - q}{\alpha (1 - q)} \qquad [20]$$

Example: Consider a boiler such that $\eta_p = 0.85$ and $q = 0.03$. If the duration of the heating period is 240 days and the duration of the full load period is 1500 hours, the load factor is $\alpha = 1500/5760 = 0.26$, which according to [20] and [18] yields a seasonal efficiency $\eta_b = 0.78$.

Now suppose that a thermal retrofit has been made which has reduced the heat losses of the building by 50%. If the heating system and the boiler are not modified the load factor decreases accordingly to $\alpha' = 0.13$ and the seasonal efficiency becomes worse: $\eta_B' = 0.67$.

Thus, if the heating system is not modified at the same time that the thermal insulation is improved, the energy savings will be less than they could be. In this example, 43% instead of 50%.

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APPENDIX III

ELEMENTARY ECONOMIC ASPECTS OF ENERGY CONSERVATION

This appendix presents some of the elements of the economics of energy conservation in the case where accrued debts are repayed in constant annuities. This restriction is not essential for our objectives (the comparison of the economic attraction of different conservation measures and the optimization of a set of measures), but helps to simplify the calculations. The methods described below are evidently applicable to buildings, or sections of buildings; cars or household appliances, etc.

1) Annual cost function

Consider an object whose acquisition corresponds to an initial investment of I[Fr], requires an annual maintenance cost of M[Fr/y] and has an annual energy consumption of Q[MJ/y]. Let it now be the case that one decides to proceed with a technical improvement on the object in order to reduce its energy consumption. This conservation measure necessitates a supplementary investment ΔI which will eventually increase the annual running and maintenance costs to ΔM but decrease the annual energy consumption by ΔQ. Applying the above condition that the acquired energy debt is to be paid in constant annuities implies that the total annual interest and amortization remains constant and each year the bank is payed a fixed sum:

$$\text{annuity} = \Delta I / D(n,r)$$

The discount factor $D(n,r)$ depends on the interest rate r and the duration of the loan n[y] in the following manner:

$$D(n,r) = \sum_{t=1}^{t=n} (1+r)^{-t} = \frac{1}{r} [1 - (1+r)^{-n}] \leq n \qquad [1]$$

(for very small r, D is very nearly equal to n, the number of years corresponding to the duration of the loan).

Given this notation, the annual cost function corresponding to the conservation measure appears in the following form:

$$f_a = \Delta I/D(n,r) + \Delta M - c\ \Delta Q \qquad [2]$$

In this relation we introduced the price of energy c[Fr/MJ] and the product c ΔQ represents the virtual financial gain realized by the conservation measure. To all appearances, the conservation measure is economically attractive if the cost function is negative. This means that the energy saving actually corresponds to a decrease in annual expenses. The threshold of economic attractiveness is when $f_a = 0$, and in this case:

$$\Delta I/D(n,r) + \Delta M = c\ \Delta Q \qquad [3]$$

2) Indicators and criteria of economic attractiveness

The threshold of profitability [3] depends on three parameters that can be qualified as "technical" : ΔI, ΔM and ΔQ; and on three "economic" parameters: n, r and c. In the threshold calculation if two of the economic parameters are given, the third can thus be found. In this way three indicators and three criteria of economic attractiveness can be defined.

a) the equivalent energy cost

$$c_e = (\Delta I/D + \Delta M)/\Delta Q \simeq \Delta I/n\ \Delta Q \qquad [4]$$

c_e is the equivalent cost of the conserved energy. In order for the conservation measure to be profitable, one should have:

$$c_e \leq c \qquad [5]$$

b) pay-back time (n_r)

This indicator is the minimum number of years necessary for the sum of money corresponding to the energy saved to equal the capital invested. This minimum is obtained at the threshold of profitability and thus solving equation [3] for n:

$$n_r = -\log(1 - r\ \Delta I/(c\ \Delta Q - \Delta M))/\log(1 + r) \qquad [6]$$

To a first approximation

$$n_r \simeq \Delta I/(c\ \Delta Q - \Delta M) \qquad [7]$$

In order for the conservation measure to be attractive one should have

$$n_r \leq n \qquad [8]$$

and n cannot be chosen greater than the physical life-time of the given object or the duration of the loan as determined by the banks.

c) internal rate of return

This indicator corresponds to the interest rate on an investment which would yield a financial return equal to the nett annual savings due to the conservation measure, or c ΔQ - ΔM. This rate is obtained by solving equation [3] for r, but unfortunately this cannot be done analytically. It is nonetheless possible to make the calculation with the help of tables or a programmable pocket calculator, and to a first approximation the following formula can be used:

$$r_i \simeq (c\ \Delta Q - \Delta M)/\Delta I - n^{-2}\Delta I/(c\ \Delta Q - \Delta M) \qquad [8]$$

In order that the conservation measure is economically attractive, the condition is

$$r_i \geq 0$$

However, for the investment to be attractive to a potential invester, it is necessary that r_i be greater than a reasonable interest rate, such as that used for the repayment of bank loans:

$$r_i > r \qquad [9]$$

3) Minimization of total annual cost

The total annual cost method is an optimization method which consists of minimizing the sum of the annual energy related investment, operation and maintenance costs:

$$F = I/D(n,r) + M + c\ Q \qquad [10]$$

This method is best applied to simple cases where the time variation of energy costs and the other economic parameters can be ignored.

4) Minimization of life cycle cost

The minimum life cycle cost method allows for the optimization of all spending related to the costs of owning and operating product. The life cycle cost is calculated by adding to the initial purchase price the sum of all the utilization costs that accrue to the item during the course of its economic life. In order for this concept to make sense it is necessary to take into account that these utilization costs are being distributed throughout the life of the product. Thus the expenses must be "discounted", meaning that one calculates for each expense paid t years after an initial payment, its present worth value at the time $t = D$ corresponding to the initial payment. Thus, for an expenditure D_t; in the year t, its present worth value will be :

$$D_t = D_0(1+r)^t \quad \text{ou} \quad D_0 = D_t(1+r)^{-t} \qquad [11]$$

In effect, D_o is the amount that could have been "banked" at an interest rate r at time $t = 0$ in order to have an amount D_t in the year t.

The simplest case is that of a product with an initial cost I and with a use that corresponds to an annual fixed cost M. Its life cycle cost is thus:

$$LCC = I + \sum_{t=1}^{t=n} M(1+r)^{-t} \qquad [12]$$

Using the definition of the discount factor [1], one obtains

$$LCC = I + M \cdot D(n,r) \qquad [13]$$

and used in this context D(n,r) is called the "present worth factor".

In in addition, the use of that product corresponds to an annual energy expense Q, the rate of energy price increase must also be included in the calculation. Supposing that the increase of the energy cost c is e% per year, the present worth value of the energy expense for the year t will be:

$$E_t = c(1+e)^t\ Q(1+r)^{-t} \qquad [14]$$

The corresponding term of the life cycle cost can be written in the same form as [1]; thus:

$$\sum_{t=1}^{t=n} E_t = c \cdot Q \cdot D(n, \frac{r-e}{1+e}) \qquad [15]$$

Therefore, for a product use with a fixed cost and a varying energy cost, the life cycle costs appears as follows:

$$LCC = I + M \cdot D(n,r) + c \cdot Q \cdot D(n, \frac{r-e}{1+e}) \qquad [16]$$

Until now we have considered only one product. In the general case, a building for example, the total life cycle cost will be the sum of terms corresponding to each of the components:

$$LCC = \sum_i LCC_i(I_i, M_i, Q_i, c_i, e_i, n_i, r_i) \qquad [17]$$

I_i : the initial capital investment for the i_{th} component;

M_i : the corresponding fixed annual use costs;

Q_i : the corresponding annual energy consumption;

c_i : the corresponding actual energy price (oil, electricity...);

e_i : the energy price increase rate;

n_i : the duration of the economic life-time of the component;

r_i : the discount rate.

For each of an item's components the parameters will be generally different. By choosing appropriate values for e and r, both inflation and the real increase in the price of energy can be taken into account. The total life cycle-cost can thus include all these parameters and its minimum will correspond to the maximum economic profitability.

In order to illustrate a life cycle-cost calculation and its use to optimize a conservation measure, take as an example the determination of the optimum thickness of an insulation. Let I_1 and Q_1, represent the cost and energy loss by transmission corresponding to an initial thickness l_1. For a thickness l_1 one will have

$$I = I_1 \, l/l_1$$

$$Q = Q_1 \, l_1/l$$

The life cycle cost will be:

$$LCC = I_1 \, l/l_1 + c \, Q_1 l_1/l \; D(n, \tfrac{r-e}{1+e})$$

The minimum of this function is obtained simply by cancellation of its derivative, which yields:

$$l_{opt} = l_1 \sqrt{c \, Q / I \;\; D(n, \tfrac{r-e}{1+e})}$$

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BIBLIOGRAPHY

Conferences

A large number of recent studies to which we refer have been presented in the conferences listed below and for which we provice an abbreviation to be repeated in the reference list.

EUE : Efficient Use of Energy (the APS Studies on the Technical Aspects of the More Efficient Use of Energy) AIP Conference Proceedings, No 25. American Institute of Physics, Inc. New York/1975.

IC : Indoor Climate, Proceedings of the First International Indoor Climate Symposium in Copenhagen, August 30 - September 1, 1978.

ECBE : Energy Conservation in the Built Environment. Proceedings of the Second International CIB Symposium on Energy Conservation in the Built Environment, May 28 - June 1, 1979, Copenhagen, Denmark. Danish Building Research Institute. 6 volumes.

CEUF : Changing Energy Use Futures. Proceedings of the Second International Conference on Energy Use Management, October 22-26, 1979, Los Angeles, California. Pergamon Press. New York/Paris 1979. 4 volumes.

BRWW : Building Research World Wide. Proceedings of the Eighth CIB Triennial Congress, June 1980, Oslo, Norway. Norvegian Building Research Institute. 3 volumes.

WFH : Wärmschutz-Forschung im Hochbau. Schweizerisches Status-Seminar, 24 October 1980 EMPA, Abteilung Bauphysik, 8600 Dübendorf.

EENB : Economies d'Energie et Energies Nouvelles dans le Bâtiment. Expériences et Résultats. Séminaire: Formation Universitaire Continue des Ingénieurs et des Architectes, Genève, 31 octobre 1980.

NECT : New Energy Conservation Technologies and their commercialisation, International Energy Agency, Berlin 6-10 April 1981.

Addresses of the main research groups and organizations quoted

The list below gives in alphabetical order the addresses of the Swiss research groups as well as the main organizations quoted in this study.

In the list of references which follows, the circled numbers refer to this address list.

---

(1) AIC - Air Infiltration Center
Old Bracknell Lane
Bracknell, Berks,
RG12 4 AM
England

(2) AIE - Agence Internationale de l'Energie
2, rue André-Pascal
F 75775 Paris Cédex 16 Tél. 524'82'00
Pour la Suisse, p.a. OFEN, 3003 Berne

(3) AMI S.A.
12, chemin du Salève
1004 Lausanne Tél. 021/24'53'06

(4) ATAL - Amt für technische Anlagen und Lufthygiene
8090 Zurich Tél. 01/259'29'85

(5) BASLER & HOFFMANN
Ingenieure und Planer AG
Forchstr. 395
8029 Zurich Tél. 01/55'11'22

(6) BBS - Balzari Blaser Schudel
Ingenieurs et planificateurs
Krambungstrasse 14
3006 Berne Tél. 031/44'69'11

(7) Commission Cantonale en Matière d'Energie
Département de l'Economie Publique
14, rue de l'Hôtel-de-Ville
1211 Genève 3

(8) CUEPE - Centre Universitaire d'Etude des Problèmes de l'Energie
5, rue Saint-Ours
1205 Genève 022/20'93'33

(9) EDMZ - Eidgenössische Drucksachen und Material zentrale
3000 Berne

(10) EIR - Eidg. Institut für Reaktor forschung
Abt. Wärmetechnik
5303 Würenlingen

(11) EMPA - Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie, Bauwesen und Gewerbe.
Laboratoire fédéral d'essai des matériaux et Institut de recherche industrielle, Génie civil, Arts et Métiers
Uberlandstrasse 129
8600 Dubendorf Tél. 01/823'55'11

(12) EMPA
9000 St-Gallen

EPFL - Ecole Polytechnique Fédérale Lausanne

(13) Institut de Thermique Appliquée (ITA)
1015 Lausanne Tél. 021/43'35'06

(14) Laboratoire des Matériaux Pierreux
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(15) Laboratoire de physique théorique
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(16) Groupe de Recherche en Energie Solaire
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(17) Institut de Recherches sur l'Environnement Construit (IREC)
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(18) Institut de Thermodynamique
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(19) Institut de Production de l'Energie (IPEN)
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EPFZ - Ecole Polytechnique Fédérale Zurich

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(21) Institüt für Thermodynamik, und Verbrennungsmotoren
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(22) Laboratorium für Festkörperphysik
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(23) Institüt für Apparatebau und Electrotechnik
PES D 12
8005 Zurich Tél. 01/47'96'20

(24) Institüt für Mess- und Regeltechnik
8092 Zurich

(25) Institüt für Hygiene und Arbeitsphysiologie
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FIGURES

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TABLE CAPTIONS

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