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Feasibility of energy saving renovation measures in urban buildings The impact of energy prices and the acceptable pay back time criterion

Agis M. Papadopoulos*, Theodoros G. Theodosiou, Kostas D. Karatzas

Laboratory of Heat Transfer and Environmental Engineering, Department of Mechanical Engineering, Aristotle University Thessaloniki, GR-54006 Thessaloniki, Greece

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Abstract

The energy renovation of existing buildings is an important tool for the reduction of energy consumption in the building sector, the improvement of prevailing indoor thermal comfort conditions and also for the improvement of environmental conditions in urban areas. At the same time, it is a technical, economic and social problem, due to the way in which many cities have been built and the restrictions imposed by economic constrains that tantalise most countries in South-Eastern Europe, and also Greece. It applies particularly in Northern Greece, with its cold and prolonged heating season, where a series of studies was carried out since 1994 to approach the problem and develop viable proposals. Public and mixed-use buildings form a significant part of the building stock and are therefore a primary candidate for energy saving measures, especially as they also play the role of a 'pilot-demonstrator' for the private owned buildings. However, due to the low energy prices that prevailed over the last 10 years, and as energy saving measurements are capital intensive investments, little was done in that direction. The recent sharp increase in oil prices proved that this was a short-sighted policy. In the following paper are presented the results of a study that aimed to determine the potential of energy saving renovation measures, in a representative sample of buildings under realistic conditions, to evaluate the feasibility of these measures, and also the way in which this feasibility is being analysed, under the rapidly changing economic conditions.

Keywords: Urban buildings; Energy renovation; Insulation; Heating system; Feasibility and economic criteria

1. Introduction: the climatic and energy features of the sample

The building sector in Northern Greece absorbs 31% of the final energy demand ranking second after the transport sector, in contradiction to the national energy balance, where industry consumes more than the building sector. This deviation is attributed to the climate, which is partly Mediterranean and partly continental, influenced by the rough Balkan winter. The city of Thessaloniki, which is located by the sea and features 1.05 million inhabitants out of the total 2.1 millions of the region, has climatic characteristics comparable to those of Toulon in France. There are, however, cities located in the mountainous inland like Florina, that justify the term continental climate. Data for these cities are presented in Table 1 [1].

* Corresponding author. Tel.: +30-31-996011; fax: +30-31-996012.
E-mail address: agis@vergina.eng.auth.gr (A.M. Papadopoulos).

2. Main features of the existing building's stock

A series of studies carried out over the last decade have shown that the improvement of the energy behaviour of existing buildings is a key factor for the rationalisation of the energy consumption in the building sector. This applies to Greece, as well as to many other European countries, where the dominant majority of the buildings are only insufficiently or not at all thermally insulated. This results in an average annual specific consumption, for space heating only, of 130–180 kWh/m^2, instead of the 80–110 kWh/m^2 that would be necessary if the buildings had been properly insulated, i.e. according to the valid legislation [2–4]. Compared to the regulations prevailing in other European countries, like Germany where values of 70 kWh/m^2 are the standard since the mid-nineties, this is a disappointing performance [5]. Still, due to the low energy prices between 1991 and 2000, this poor performance remained largely unnoticed. Interest shifted from the reduction of heating to the reduction of cooling loads, mainly by means of altering the electricity

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Table 1
Climatic data of Thessaloniki and Florina in Northern Greece compared to those of Toulon

	Degree–days ($DD_{ref\ 18\ °C}$)	Average temperature (°C)	Average minimum temperature (°C)	Design minimum temperature (°C)	Solar radiation (kWh/m^2)	Hours of sunshine (H)
Thessaloniki	1725	15.6	4.2	−2	1404	2555
Florina	2542	13.2	−3.4	−11	1230	1905
Toulon	1790	15.1	4.5	−2	1490	2710

pricing policy. The main issue over the last decade was that of cooling and air-conditioning in the summer, which lead to significant problems as the occurring peak-load demand increased by more than 55% over the last 10 years [6]. However, the real 'threat' appeared as late as in the fall of 2000: As retail oil-prices almost doubled within a year and electricity retail prices increased by an average of only 12%, the buildings' tenants, have started to use air-conditioning units, mostly of the split-type heat pumps, also for space heating. This might make sense from an economic point of view for the tenants, but presents a serious problem both for the national economy and the environment, due to the low efficiency, and the limited installed capacities, of the lignite-fired power plants operational in Greece. It also gives reasons to doubt whether it will be possible to reduce the CO_2 emissions, as foreseen by international agreements. From the aspect of rational energy use it is a completely false approach, as it focuses only on the search for a cheaper energy form, instead on the effort to reduce energy consumption in combination with providing cheaper energy. Finally, from the long term economic perspective, it is also a narrow minded policy, because it inevitably leads to higher running cost of the buildings by trying to avoid the initial investment needed to reduce energy consumption.

Within the series of research projects carried out with the participation the Aristotle University Thessaloniki, the possibilities of implementing energy saving measures in more than 90 buildings in Northern Greece were examined in the period 1994–2000. Out of these buildings a sample of 42 residential, public and mixed use buildings has been formed as representative, covering a wide range of ages and construction arts, from the end of the 19th century up to the early 1990s. The buildings include residences and/or public services, private enterprises, educational institutes, banks and a hospital. The distribution of the buildings' ages and uses is depicted in Fig. 1 and is, in terms of the buildings useful surface, fairly representative of the entire buildings' stock, as it was registered by the 1991 general national census, that presents the most recent data available.

2.1. Energy behaviour of the buildings

The energy audits carried out confirmed the significance of space heating in the buildings' energy balances. The energy consumption of the buildings included in the sample are presented in Fig. 2.

According to the date of construction three different groups can be determined: buildings dating from the end of the 19th century until 1940. This class consists of two major sub-groups: there are the rather few in numbers large buildings with an important 'monumental' architectural value, usually housing public services and authorities, offices, museums etc. where the options for intervention on the buildings' shells are rather limited. These buildings have been renovated over the years; contemporary heating systems have been installed and in some case also air conditioning systems. Their average annual space heating consumption of 183.5 kWh/m^2 can be regarded as acceptable, given their age and particularities. Then, there are the residential and mixed-use buildings, met mainly in the smaller cities, the villages and the rural areas, which are significant in number, but small in size. These are the buildings where space heating is covered mainly by means of wood-fired stoves, which results in low energy consump-

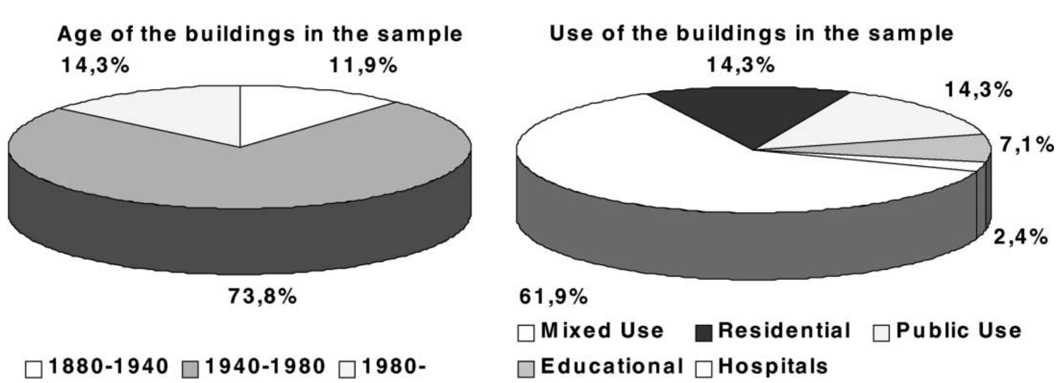

Fig. 1. Distribution of the buildings' age and use as included in the sample.

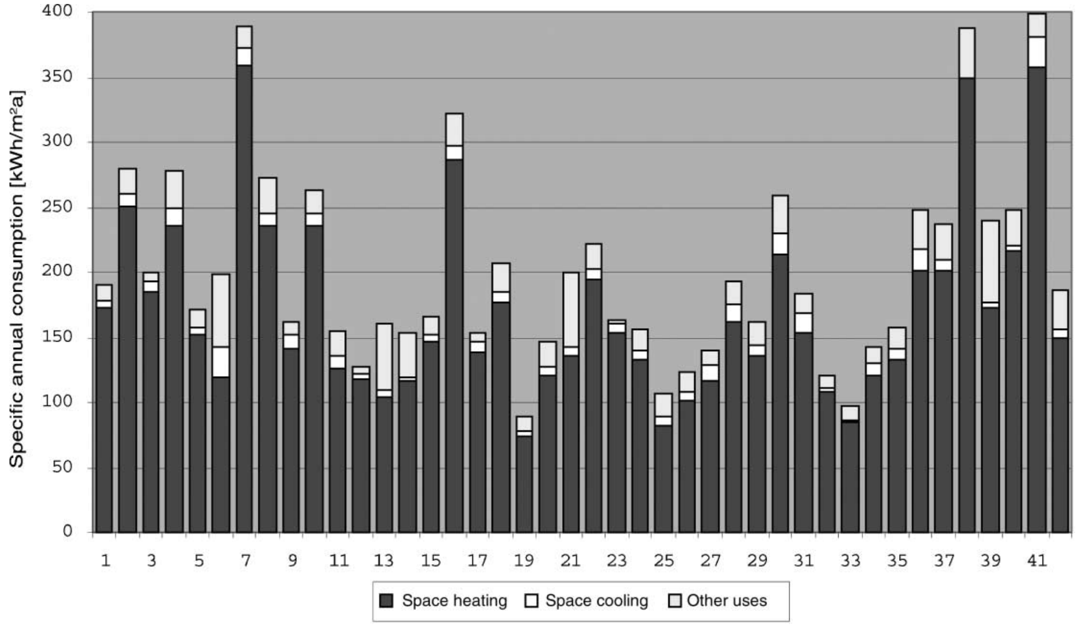

Fig. 2. Specific annual energy consumption with respect to its use.

tion and respective poor prevailing comfort conditions. It is very difficult to obtain detailed data on the energy consumption and the condition of those buildings, which are anyway progressively replaced by new constructions. It should be noticed, however, that they are not always torn down but are used as warehouses, stores or small workshops.

The second, and most important group, consists of buildings which were constructed after the second World War until the late 1970s, and they represent the major part of urban buildings. Most of them are 3–7 storeyed mixed-use buildings, housing shops or enterprises on the ground floor and residences on the other floors. The change of land usage in the cities evolving in the nineties, led to the gradual change of use of these buildings, which in the city centres house almost exclusively shops and enterprises or public services. Those still housing residences have not been substantially renovated, which led to a steady decline of the living conditions and also their market value. Their energy performance is poor, as it can be seen in the data presented in Fig. 3. They need on average 167.9 kWh/m^2 annually to ensure satisfactory comfort conditions, though some of them in the sample needed no more than 80 kWh/m^2 per annum. On the other hand, annual values of up to 360 kWh/m^2 were monitored in one case. This was a hospital building with a 24 h per day operational pattern, constructed in 1952 without any thermal insulation with a U_{overall}-value of 3.21 W/m K, located in one of the coldest cities of the region.

Finally, there is the third group of buildings, consisting of those constructed after 1980, when thermal insulation became mandatory, which present a fairly good energy behaviour, as represented in the average annual value of 100.4 kWh/m^2. The lowest values of 50–60 kWh/m^2 per annum were monitored in well insulated buildings in the city

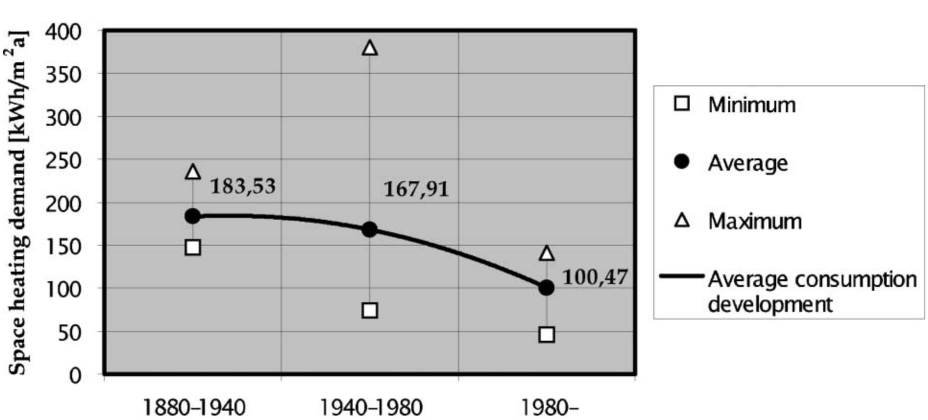

Fig. 3. Specific space heating demand with respect to the buildings' age.

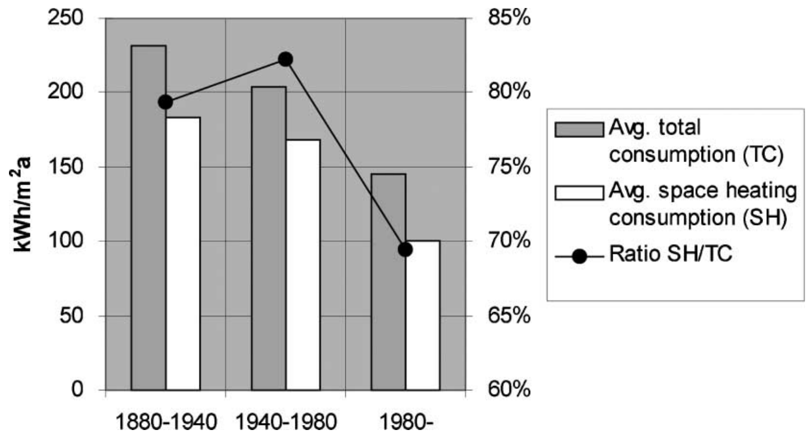

Fig. 4. Average specific annual space heating requirements compared to the total consumption.

of Thessaloniki, whilst the highest of 130–150 kWh/m^2 in only partially insulated buildings in colder cities.

On the whole, the participation of heating demand in the total energy balance is dominant, and this is justified by the effort to achieve the fairly good thermal comfort conditions monitored, as it will be discussed in the following paragraph. Space heating is responsible for approximately 80% of the total consumption in the pre-war buildings and in those built before 1980, whilst it accounts for only 70% in the modern, insulated ones, as it can be seen in Fig. 4.

2.2. Prevailing thermal comfort conditions

Thermal comfort conditions were monitored in the buildings surveyed, in order to evaluate the buildings' behaviour in correlation with their energy consumption. The measurements consisted of weekly air temperature and relative humidity measurements, as well as short time air velocity and surface temperature measurements. The measurements were carried out in the second fortnight of January and the first and second week of July, when statistically the most extreme climatic phenomena of the winter and summer period respectively are met, and the services and enterprises are fully operational. The educational buildings were an exception, since they were monitored in May and June, as they are not operating in July and August. The presentation of the detailed results of this part of the research falls not within the scope of this paper, but a brief comment is thought to be of interest. The typical weekly average values of the internal air temperature and relative humidity conditions prevailing in each building are presented in Fig. 5 for the winter (left) and the summer period (right) respectively. Of the 42 buildings only five appear to have an unsatisfactory behaviour in winter, and that by a close margin. A total of 20 buildings present a very good behaviour and the remaining 17 a satisfactory. The increased energy consumption for

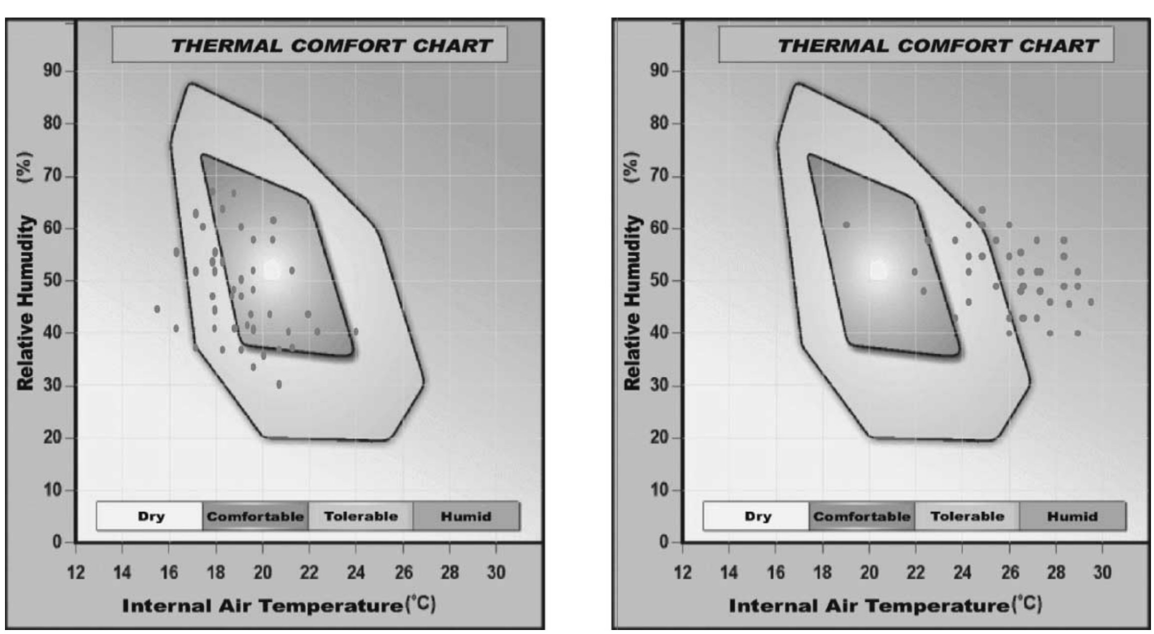

Fig. 5. Thermal comfort conditions prevailing in the winter (left) and in the summer (right).

space heating can be, in that sense, justified, as it enables the establishment of good or acceptable comfort conditions. A minor difficulty determined was the low relative humidity monitored in some buildings (below 40%), which was due to reduced ventilation combined with the drying effect of the heating system's radiator panels.

The comfort conditions situation monitored in the summer period is reversed: good conditions were recorded in only three buildings, which are the only ones almost fully air-conditioned. Another 11 buildings presented satisfactory conditions: four of those are partly air-conditioned whilst the other seven are buildings with reasonably dimensioned openings, located in smaller cities in the inland, justifying the argument of the reduced demand for air-conditioning in such cases. The main problem lies in the 27 buildings where high temperature and humidity values were recorded, leading to poor comfort conditions. Most of these buildings were located in the city centres, where the potential for natural ventilation is constrained by traffic noise (exceeding in Thessaloniki city centre 76 dB in most main streets and 80 dB in some avenues), but also to increased air pollution [7].

3. Determination of the energy consumption factors

The next point of interest is to determine the reasons for the energy consumption monitored, in order to be able to assess the potential for energy savings. Four were the main factors considered in the study. Three referred to the building's shell, namely the size of the buildings, their surface to heated volume ratio *F/V*, the existence of thermal insulation. The fourth referred to the type and condition of the heating system. There are, of course, other factors influencing a building's heating requirements, like the orientation and the exposure to insolation and local winds, etc. which are important to consider in the detailed study of a specific building, but these are difficult to quantify in the study of a large sample. Furthermore, the different operational patterns occurring in mixed-use buildings complicate the energy analysis: the complexity in the study of parameters for ventilation and infiltration, as well as for the profiles of internal sensible and latent loads can lead to inaccuracies when trying to apply a generalised computational algorithm. Hence, the use of the four main parameters mentioned was judged as sufficient to provide a solid base for the assessment of the energy saving potential and feasibility.

3.1. Design parameters

The size of the buildings influences consumption, though not in a straight-forward linear way and not significantly, as it can be seen in Fig. 6. Small buildings, with useful areas of less than 1000 m^2, are more inefficient than the medium sized ones, whilst the big ones, with useful areas exceeding 3000 m^2, appear to have the highest specific consumption. The differences are, in any case, not exceeding 5%. The same remarks can also be made for cooling energy consumption, though this issue has to be treated with some care, as the propagation of the air-conditioning retrofitting is still gathering momentum and an even steeper increase in the installed capacities and consumption is expected to coming years.

The second main parameter considered was the surface to heated volume ratio *F/V*. Its impact on space heating consumption is definitely significant, as consumption is increasing in an almost linear way with the increase of *F/V*, as shown by the regression analysis. The additional increase, noted in Fig. 7, for buildings featuring an *F/V* ratio higher than 0.6 is due to the fact, that out of the 15 such buildings, only one was insulated.

3.2. Structural parameters

As far as the existence of thermal insulation on the examined buildings' shells, which is depicted in Fig. 8, some observations can be made, considering as a satisfactory insulation the one corresponding to the contemporary Greek regulation. Though the opaque elements of the pre-war buildings feature no insulation at all, in 40% of the sample

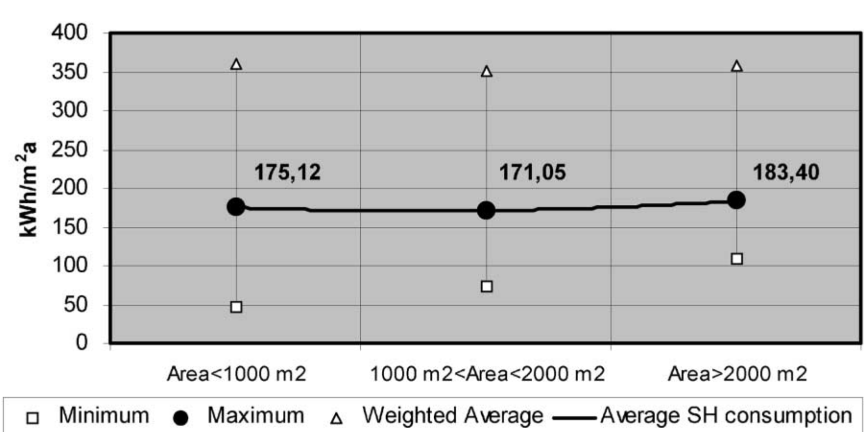

Fig. 6. Distribution of specific space heating consumption with respect to the buildings' area.

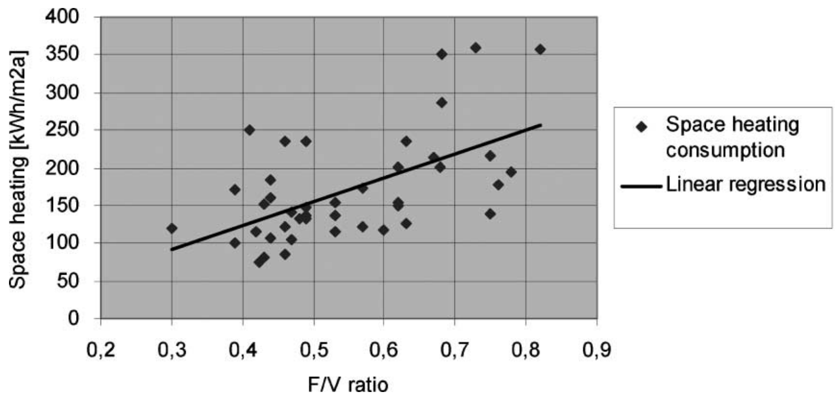

Fig. 7. Space heating consumption with respect to the *F/V* ratio.

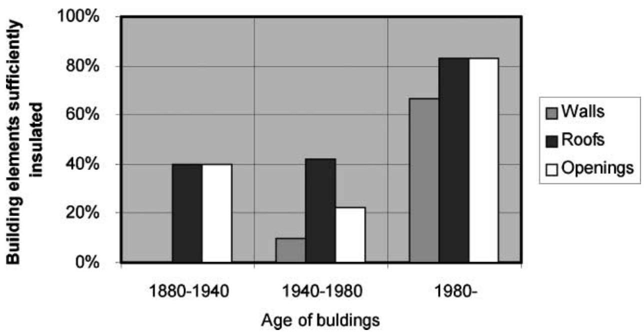

Fig. 8. Sufficiency of insulation with respect to the buildings' age.

their roofs have been partly insulated and the old windows replaced by new, double glazed ones. Considering the earlier mentioned architectural and other particularities, the situation can be assessed as quite satisfactory. This is not the case in the buildings constructed between 1940 and 1980, which are practically uninsulated at their walls. Windows have been replaced to a limited extent (22%) and the roofs have been insulated in 42% of the cases, mainly during reconstruction due to dampness problems. A further point of interest is, that even in the newest buildings, the regulation seems not to have been applied, as some 35% of the buildings had inadequate insulation at the walls, or in one case none at all. These results coincide on the whole by those of previous, extended studies considering the Greek building stock [8,9].

The resulting heat losses distribution is presented in Fig. 9. When considering only the post-war buildings, the breakdown of the thermal losses, shows, that ventilation and infiltration account for 30.8–40.6% of the total heating demand, the higher figure being as expected monitored in the insulated buildings, as their transmissivity losses are, in absolute terms, lower due to the existence of insulation.

Transmissivity losses account for 23.7–21.9%, a figure fairly high, but reasonable as openings have become consistently larger on the buildings' facades over the decades, offsetting so the reduced *U*-values of the double glazed windows. Finally, the situation has improved significantly in the sensitive area of the roof, reducing losses from 11.2 to 7.7%. The introduction of extruded polystyrol and high quality bituminous membranes in the early eighties presented the engineers and constructors with an easy applicable and fairly cost efficient solution, in the form of the inverted flat roof.

3.3. Condition of the space heating systems

One of the most disappointing results of the research concerned the condition of the space heating systems, which were evaluated according to their boiler's efficiency (minimum foreseen 80%, with an allowance of 5% less for older systems), the existence and condition of thermal insulation at the distribution grid and the existence of controls. As it

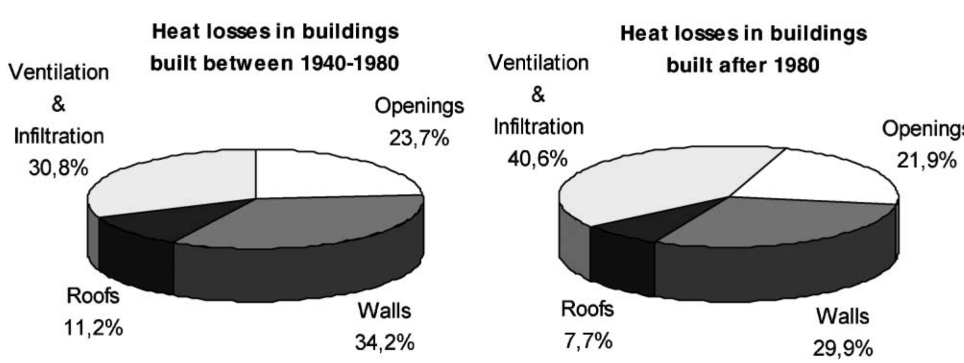

Fig. 9. Distribution of the heat losses with respect to the buildings' age.

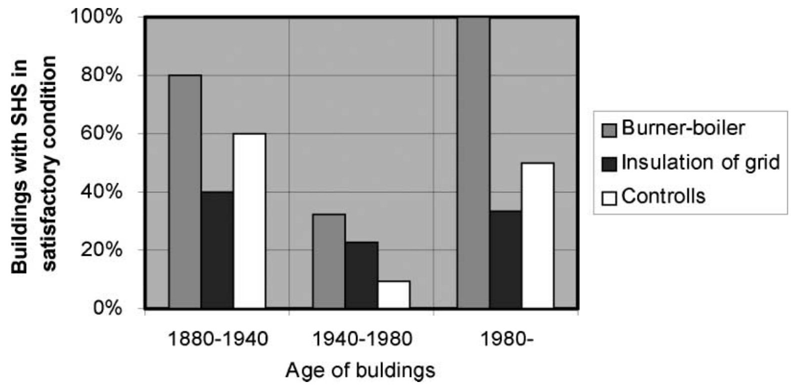

Fig. 10. Conditions of the buildings' space heating systems, with respect to their age.

can be seen in Fig. 10, the situation in the main group of buildings (1940–1980) is very poor indeed; only 30% of the buildings featured a reasonably efficient boiler, whilst the average efficiency of this group was 68%. The combination of age and poor maintenance leads to these results. The grid and the controls were found to be in an even worse condition.

The oldest group of buildings seems to feature surprisingly good heating systems, mainly due to the fact that these big buildings were renovated in the late 1980s to mid 1990s, with new systems installed, which are since then fairly well maintained. The most recent buildings feature arguably satisfactory burners and boilers, though they lack the controls (like three-way mixing valves and compensating thermostats) which should have been installed, as they were foreseen by the regulation since 1982 and they were available in the market.

4. Energy saving measures and potential

From the previous paragraphs result two major areas for energy savings in the buildings: improvement of the central heating systems and improvement of the buildings' shell insulation. There is indeed a significant margin for improvement in the performance of the majority of the heating systems, which implies better insulation of the hot water distribution grid, the installation of state of the art controls for the systems' operation and, in most of the building constructed in the 1960s and 1970s, the replacement of obsolete boilers and burners. The last measure can be combined with the introduction of natural gas in the Greek energy system, which begun in the Spring 2001. As a whole, in 37 out of the 42 buildings examined, such improvements were necessary. By implementing them savings between 4% and 11.5% would be achievable.

As far as the thermal insulation of the buildings' shell is concerned, the main chances for interventions were located:

1. in the insulation of the vertical building elements, in most cases by retrofitting externally 3–5 cm of thermal insulation covered by plaster;
2. in the insulation of the roof, on flat roofs by 'adding' externally a 5–8 cm thermal insulation layer as an inverted roof or by adding internally the same thickness of material in case of sloped roofs;
3. by replacing the old windows with new double-glazed ones, with U-values of less than 3.2 W/m K.

It resulted that such measures were needed in 34 out of the 42 buildings. Their impact was simulated according to the experience gained from projects implemented over the last years. The minimum, maximum and weighted average results of each of the proposed measures and for the buildings of the sample are depicted in Fig. 11. The detailed results for every building are listed in Table 2.

A short note has to be made on another possible measure, the Sun-protection in order to reduce the cooling demand. It is most unfortunate, that the 'glass tower syndrome' has abolished the traditional architectural features, which were vital under the Mediterranean climatic conditions, leading to the current situation, which was predicted already in 1974 [10]. Still, the reduction of the cooling demand by retrofitting external sun-protection devices is crucial, in order to obstruct incoming solar loads in summer, although it is very difficult to adapt sun-protection systems to an existing building, without violating its initial design approach. In four cases of the examined sample it was determined, that such an intervention would be possible, leading to a reduction in the simulated cooling loads between 8% and 35.5%. However, the estimated costs were beyond the limits of a renovation measure and the architectural and structural issues arising were far too complicated to allow a consideration of such proposals. Its consideration, therefore, remained on the level of a design study and falls not within the scope of this paper.

5. Feasibility of the proposed measures

The possible savings, as presented in the previous paragraph, are those that can be achieved from the technical point of view. It is, however, a different issue whether the

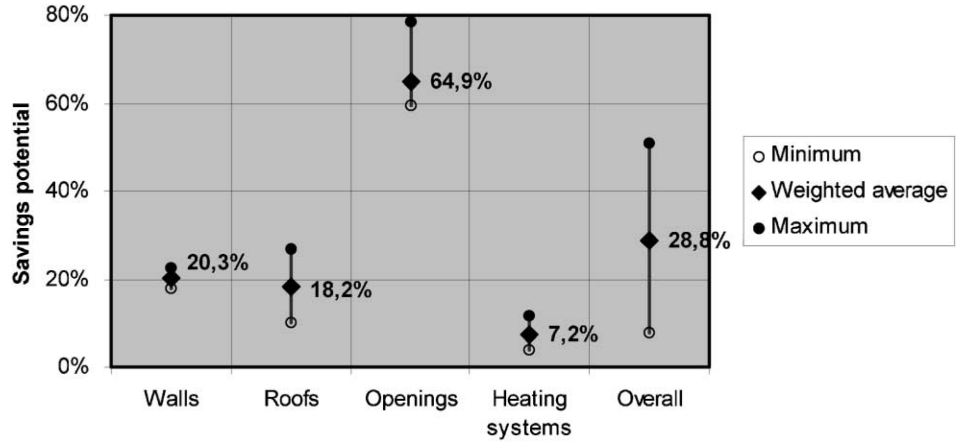

Fig. 11. Achievable energy savings compared to the initial energy consumption.

measures needed to achieve these savings are financially feasible. In order to determine this, two further parameters have to be considered: The age of the buildings, and hence its residual useful lifetime, and the cost of energy.

It has been established that buildings that are 20-years-old, i.e. which were constructed before 1980, is a serious cause for excessive energy consumption, but they are also an asset, which is beginning to devaluate for its owners. On the other hand, the energy saving potential in these buildings is significant. This applies even stronger to buildings exceeding the age of 30 or 40 years. At the same time, the conventionally accepted useful lifetime of a building is 70 years, raising serious doubts on whether it is worth considering 40-years-old buildings for a thorough modernisation. However, with the rapidly growing demand for buildings in the urban areas, particularly in the city centres, it is most likely that even older buildings will remain in use, provided they will be refurbished and upgraded. The issue of determining the deterioration of the building stock's value and the resulting refurbishment costs, combined with the resulting increase of the asset's value is a complicated one, as it is not only a function of technical factors. The Swiss Universities of Zurich and Lausanne (ETHZ and EPFL) the German Fraunhofer Institute for Building Physics and the Institute for Fincancial Studies REWESO have developed methods for assessing the optimum timing of a whole renovation or of single intervention measures [11,12]. For the purposes of this study, a useful life time of 70 years was accepted, considering in that sense the buildings exceeding this age as 'traditional' buildings, without any strict feasibility criteria applying to them.

As far as the energy cost is concerned, between 1996 and 1999 the average oil retail price in Greece was 0.031 €/kWh and the retail price for electricity 0.082 €/kWh. However, the drastic increase of crude oils prices and the surging US$/€ exchange rates lead since early 2000 to prices of 0.053 Euro/kWh and 0.091 Euro/kWh for oil and electricity, respectively. The significance of this increase for space heating, cooling, DHW, etc. is evident; the resulting annual costs are presented in Fig. 12.

It seems, therefore, appropriate to consider the series of energy saving measures that evolved, under the mentioned

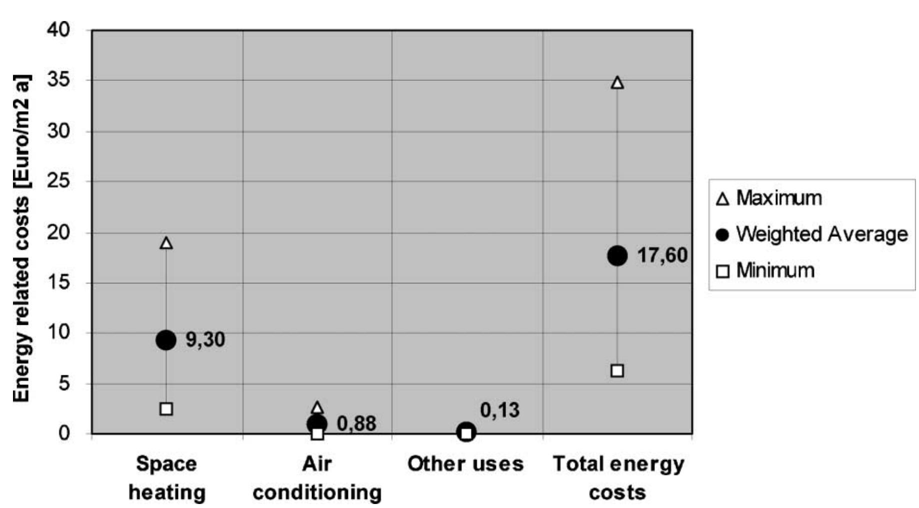

Fig. 12. Energy related costs with respect to the use.

Table 2
Main energy features of the buildings and feasibility results of the proposed measures

Building ID Number	Date of construction (year)	Use[a]	Specific heating consumption (kWh/m^2 per annum)	Savings possible (%)	Single interventions[b]				DPB (years)	SIR[c]
					Walls	Roof	Openings	Heating system		
22	1885	PB	194	19.4	×	N.n.	?	N.n.	6.8	N.A.
21	1895	PB	136	18.5	×	✓	?	N.n.	5.9	N.A.
20	1930	PB	121	19.0	?	N.n.	N.n.	N.n.	16.3	N.A.
24	1932	MU	133	28.7	×	✓	N.n.	N.n.	10.1	N.A.
23	1935	PB	154	25.9	?	N.n.	?	✓	12.5	N.A.
8	1952	E	236	51.0	✓	✓	✓	✓	3.6	3.7
38	1952	H	350	38.3	✓	N.n.	✓	N.n.	8.4	3.2
42	1962	MU	149	34.8	✓	N.n.	✓	N.n.	9.0	1.7
18	1963	MU	177	22.4	✓	✓	✓	✓	7.2	2.1
41	1964	MU	357	36.9	✓	✓	✓	✓	5.1	3.2
7	1965	PB	359	28.6	✓	✓	?	N.n.	4.8	2.9
39	1966	E	173	31.2	✓	✓	✓	✓	6.8	3
40	1966	MU	216	28.5	?	?	✓	✓	8.6	2.3
6	1968	PB	119	37.9	✓	✓	N.n.	✓	7.2	2.1
5	1970	MU	152	32.8	✓	✓	?	N.n.	5.5	3.5
4	1972	MU	235	27.8	✓	N.n.	✓	✓	13.8	2.7
19	1972	MU	74	14.3	✓	N.n.	N.n.	N.n.	11.0	2.6
10	1975	MU	236	25.6	?	×	✓	N.n.	7.6	3.4
13	1975	MU	104	21.0	✓	✓	?	N.n.	15.3	2.2
36	1975	MU	202	19.6	✓	✓	✓	✓	6.2	3.4
37	1975	E	201	17.3	✓	×	?	✓	8.3	3.2
12	1976	MU	118	17.6	N.n.	N.n.	✓	✓	16.0	1.8
16	1976	MU	286	37.2	✓	N.n.	✓	✓	8.4	3.3
17	1976	MU	139	14.3	✓	✓	?	N.n.	7.0	2
35	1976	MU	133	21.0	✓	✓	?	✓	6.5	3.2
1	1977	MU	172	31.1	✓	N.n.	?	✓	4.8	3.4
34	1977	MU	121	16.8	✓	N.n.	N.n.	✓	7.1	2.3
3	1978	MU	185	17.4	✓	✓	?	✓	5.5	3.5
14	1978	MU	116	18.3	✓	✓	N.n.	✓	16.1	1.2
32	1978	R	108	12.4	✓	N.n.	N.n.	N.n.	4.9	3.7
33	1978	MU	85	17.3	✓	✓	N.n.	N.n.	6.3	3.3
2	1979	MU	251	24.8	✓	✓	?	✓	15.2	1.3
30	1979	MU	214	7.4	✓	N.n.	?	✓	6.0	3.4
9	1980	MU	141	9.7	✓	N.n.	?	✓	4.8	3.6
29	1980	R	136	4.6	N.n.	N.n.	N.n.	✓	4.5	3.5
31	1980	MU	154	5.9	N.n.	N.n.	?	✓	3.6	3.7
11	1982	MU	126	8.3	N.n.	M.i.	N.n.	✓	16.2	1.9
15	1982	MU	147	21.3	?	✓	?	M.i.	18.1	0.9
28	1985	R	161	12.4	✓	N.n.	N.n.	M.i.	5.5	3.6
25	1986	R	82	1.1	N.n.	M.i.	N.n.	N.n.	20.3	1.5
26	1987	R	101	4.8	N.n.	N.n.	N.n.	M.i.	8.3	3.1
27	1988	R	116	7.8	N.n.	N.n.	N.n.	M.i.	5.2	3.4

[a] PB: public building, public or private services and offices; MU: mixed-use building, residences and services/enterprises/shops; E: educational building; H: hospital; R: residential building.

[b] Symbols (✓): feasible intervention; (?): necessary, but not feasible; (×): not possible to intervene; N.n.: not needed intervention; M.i.: minor interventions.

[c] N.A.: SIR values for buildings older than 70 years cannot be determined.

time and cost boundary conditions. In order to do this the depreciated payback period (DPB) and the savings to investment ratio (SIR) were used. The former is derived from the depreciated cash flow method of the net present value (NPV), as shown in Eq. (1)

$$\mathrm{NPV} = -C_{\mathrm{in}} + \sum_{t=1}^{N} \frac{\mathrm{F}_t}{(1+d)^t} + \frac{\mathrm{SV}_N}{(1+d)^N} \qquad (1)$$

where C_{in}: initial cash out-flow needed for the implementation of the renovation measure; F_t: value of the energy savings, considered as a cash in-flow for the time period (year t); SV: salvage value of the initial investment, applicable in the case of heating equipment otherwise considered as negligible; and d: capital cost rate.

In order to determine the depreciated payback period, the NPV is set equal to zero, as this is the time period for which the initial investment has been amortised, as shown in Eq. (2).

$$\mathrm{DPB} = \frac{-\ln(1 - (dC_{in}/F_t))}{\ln(1+d)} \tag{2}$$

The DPB provides the investor with an index of how fast the initial investment is being paid off, but with how efficient the investment was. In order to determine this the savings to investment ratio method is being used, as presented in Eq. (3) with the same nomenclature.

$$\mathrm{SIR} = \frac{\sum_{t=1}^{N} F_t/(1+d)^t}{\sum_{t=0}^{N} C_t/(1+d)^t} \tag{3}$$

The evaluation was carried out taking into consideration the actual material and labour cost figures (fall 2000) of carrying out the measures mentioned in Section 4. The capital cost rate used for the depreciation of the cash flows was considered to be 6% per annum. No tax deductions or any other forms of state driven incentives were considered. As far as energy prices were concerned a sensitivity analysis was carried out, covering a range of 40% of variation, considering the average 1998 prices as the reference base and the 2000 prices as a maximum increase. The results of the evaluation for the latter case are presented for each building in Table 2.

The second point of analysis was the criterion determining the acceptability of a DPB value. Traditional economics state that the DPB has to be smaller than the residual useful lifetime of the investment. In energy saving measures in the industrial sector a limit of 3–4 years is usually considered as acceptable [13]. Both values are rather inappropriate for the building sector, the former setting a time schedule too distant to be practicable, the latter being too short termed to be achievable, except perhaps is minor interventions in the heating systems. The 'middle of the road' approach is to accept a strict limit of the magnitude of 8 or 10 years, as it is the case in some national regulations or in the debated proposal for a European directive on the energy performance of buildings [14]. The DPB values in bold and italics in Table 2 are those resulting as feasible. Such a criterion has the advantages of being easily applicable and ensuring the attractiveness of the investment to the building owner, as 8 years can be considered as reasonable time frame for a building. However, as it was shown in the sample considered, there are buildings that are 10–20 years old and have therefore a residual useful lifetime of 60–70 years, but present inefficiencies due to their construction or design.

An acceptable DPB of 8 years would be far too short, if an effective renovation measure, with a DPB of 12 or 15 years, would ensure substantial energy savings for the remaining 50 years. Hence, a variable limit for the DPB criterion should be determined; the suggestion being that the DPB should not exceed one third of the residual lifetime. In that sense the residual useful lifetime 3 (RUL-3) criterion was adopted for the evaluation of the measures determined previously. The difference between the acceptability of proposed investments, according to the two different criteria, is depicted in the following Fig. 13.

If the 8 years criterion is used, the renovation of 62% of the buildings in the sample is considered as feasible, whilst, if the RUL-3 criterion is applied, the eligibility increases to 81%. Now, one might argue that the feasibility analysis has to be carried out under the most 'pessimistic' criterion, in order to ensure the soundness of the investment. In that direction it has to be determined what the impact of a fluctuation of energy prices, i.e. the single most important variable influencing the feasibility of the investment would be, and how it would affect the acceptability criteria. A sensitivity analysis was carried out, allowing energy prices to increase at 10% steps from the 1998 to the 2000 values. The changes in the resulting feasibility for the buildings of the sample are presented in Fig. 14. Three criteria were used: the 8 years DPB period, the RUL-3 period and, for the sake

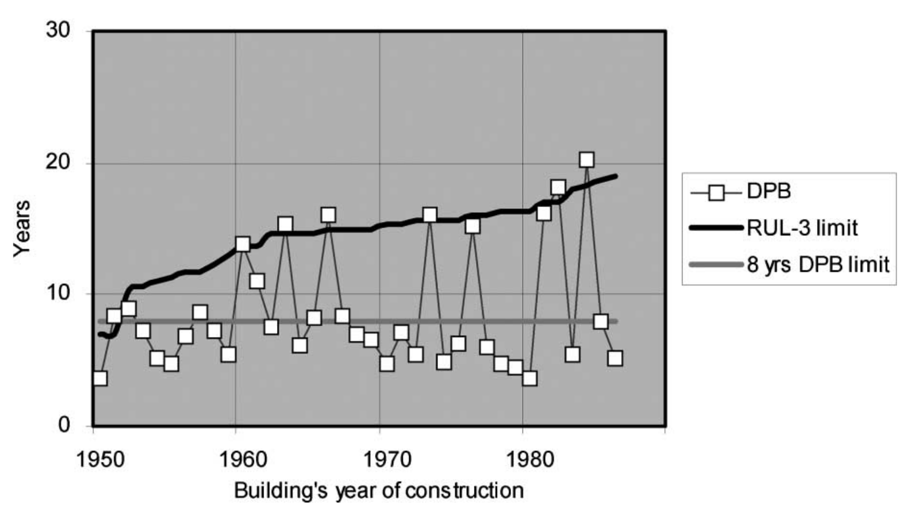

Fig. 13. Depreciated payback periods compared to the 8-years payback and the RUL-3 criteria.

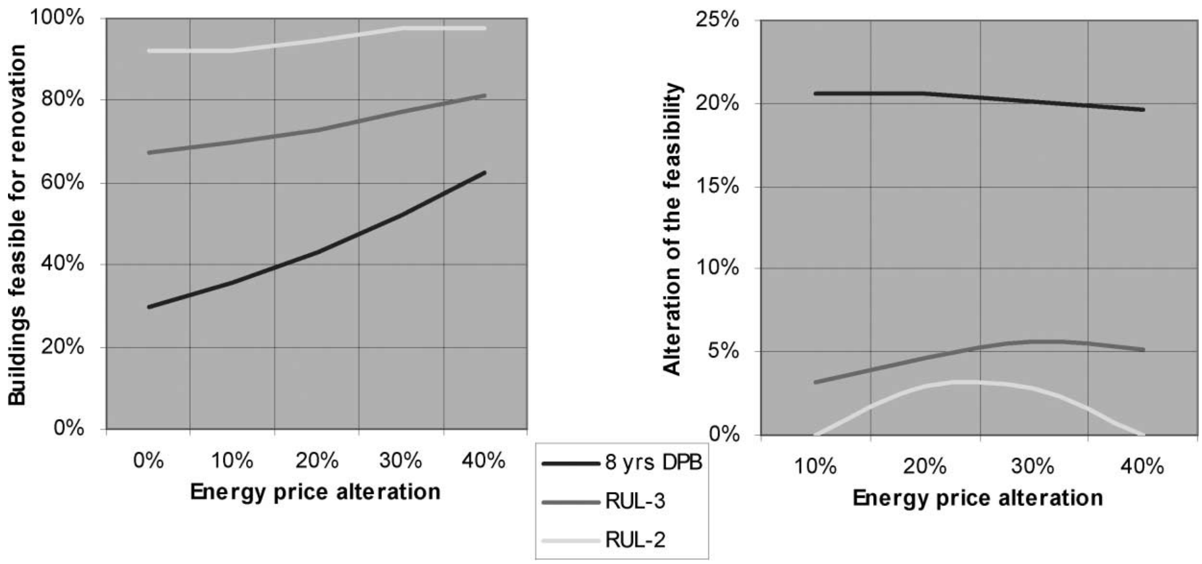

Fig. 14. Impact of energy price alteration on the feasibility of renovation according to the three criteria.

of the analysis, a RUL-2 period, corresponding to half the residual lifetime of the buildings. As it can be seen on the left side of the figure, the 8 years DPB period criterion is more sensitive to the energy price increase, the RUL-2 is rather insensitive (almost the same number or proposed investments remain feasible, indifferently of the energy price alterations) and the RUL-3 presents an intermediate approach. The linearity of the response becomes more evident in the right part of the Figure, where the feasibility alteration is plotted versus the energy price alteration, demonstrating an average of 20% differentiation in the feasibility for every 10% differentiation of the energy price. RUL-3 can also be considered as satisfactory, as it responds fairly close to linear, but with a smaller gradient.

The conclusion that can be drawn, is that the concept of a strict DPB criterion is not only favourable for reasons of practicability, but also for its reasonable sensitivity to energy price alterations. Still, it has to be mentioned that it places investments in new buildings into disadvantage compared to the use of a variable time criterion, as the RUL-3.

6. Conclusive remarks

The issue of energy renovation measures in existing buildings is important and complex. The energy saving potential is significant, but so are the financial and regulatory problems to be overcome. The way in which cities were built in the 1960s and 1970s led to a situation whereby effective energy renovation measures are often leading to forbidding costs and unacceptable economic results, or at least so it seemed over the last decade. However, the inefficiencies in the thermal protection of the buildings' shells and in their heating systems were proven within the framework of a series of studies carried out in Greece. So was the average saving potential of 28% referring to the present condition and with realistic, practicable measures involved.

The latest increase in energy prices is a very good reminder of how shortsighted the policy of neglecting to implement such measures was. Precious time and even more precious energy resources have been used up, whilst the energy saving mentality of the 1970s and 1980s faded, without any significant results. Residential and mixed-use buildings are particularly suitable candidates for an enforced application of energy renovation measures, as they form the bulk of the Greek building stock and also are significant energy consumers. However, the terms under which the feasibility of such measures will be evaluated have to be determined carefully, not allowing for energy conserving enthusiasm, or for too conservative monetary scepticism. The latter applies particularly in the case of fairly new buildings with deficiencies. In any case, even if energy prices will decrease again in the near future, the environmental impact of neglecting to carry out the measures needed to upgrade the existing building stock, is far too important to be left without consideration.

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