ENERGY, ECONOMIC, AND ENVIRONMENTAL ASSESSMENT OF REFURBISHMENT PROPOSALS IN THREE GREEK SCHOOLS

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ABSTRACT

The paper refers to the results of a European SAVE Project aimed at providing technically feasible and economically viable solutions for public school buildings in Greece using energy conservation, passive heating-cooling and daylighting techniques. The case of refurbishment proposals for three characteristic schools, situated in different climatic zones, is examined. The proposed solutions include techniques and equipment applicable to the building envelope and services, which are intended to upgrade human comfort conditions year round by reducing at the same time the energy demand for central heating and lighting. The effect on energy conservation and comfort is analysed with thermal simulation software. The economic assessment of the proposed solutions during their life cycle is elaborated using Discounted Cash Flow analysis (DCF) indices. The environmental benefit from the proposed solutions is assessed through the reduction of main pollutant emissions and primary energy input.

Keywords : Schools, comfort, energy saving, technoeconomic assessment, passive heating, passive cooling

NOMENCLATURE

DPB	Discounted Pay Back Period (years)
NPV	Net Present Value (Drs)
K	Capital Investment Differential Cost (Drs)
F	Annual Operational Economic Benefit from energy saving (Drs/year)
N	Economic Life Cycle of energy saving solution (years)
d	Discount Rate
Subscripts	
NE	National Economy
t	Year of Operation

INTRODUCTION

In Greece there are more than 15,000 schools with facilities for more than 1,600,000 pupils. The mean total final energy consumption for heating and lighting of schools is estimated around 270,000 MWh per year, that is equivalent to 16,300 tonnes of fuel oil and 78,000 MWh electricity. The resulting annual CO_2 and SO_2 emissions are 150,000 and 1,000 tones per year respectively. The average energy consumption for heating is 92 kWh/m^2 heated floor area, which is a high amount, taking into account the generally mild climate of the country and the occupancy characteristics of schools. Furthermore, this consumption does not cover the actual needs, as in most schools comfort conditions are often not met. The last is justified especially from the following facts which have been recorded:

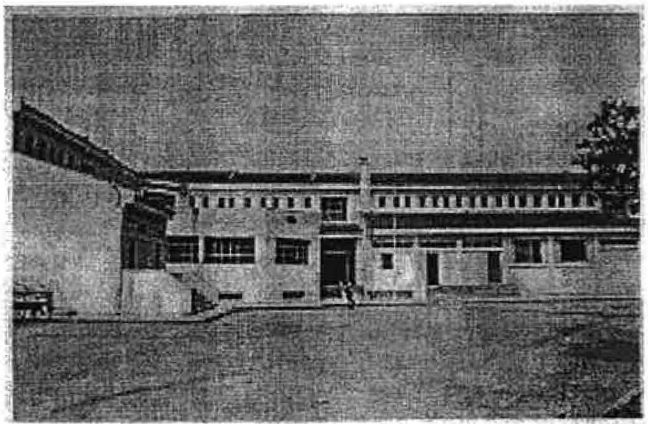
- Uncontrolled ventilation during winter
- Poor lighting conditions due to unequal distribution of daylight, which results in glare and inadequate lighting at the far end of classrooms
- Very high indoor temperatures from spring to autumn, especially in the warmest climatic zones.

Within the framework of the E.C./DG XVII SAVE Programme, the Passive Solar and Hybrid Systems Department of C.R.E.S. has conducted the project "Technical and Economic Assessment of the Refurbishment of School Buildings for Energy Efficiency and Improvement of Thermal and Visual Comfort Conditions" [1] The project was coordinated by E. Athanassakos, Head of the PSHS Dept. of CRES. Part of the project deals with the case study of three characteristic public schools situated in Greek cities of different climatic zones (Athens, Thessaloniki, Chania).

THE SCHOOL CASE STUDIES

23d High School of Thessaloniki

The school was erected in 1990, in accordance with the specifications of the Greek Organisation of School Buildings (OSK). The 2,100 m^2, two-storey building is situated in the district of Kalamaria in Thessaloniki, which belongs to the coldest climatic zone (zone C) of Greece. The school operates in too shifts, 8:00-13:30 and 14:00-19:30. Its rooms are organised in an L-shape configuration. Classrooms and the library are arranged on the external side of the L-shape, in parallel with the two adjacent crossing streets; in the internal side there are a multipurpose hall, offices, showers-toilets, and circulation corridors. The structural elements of the building are of reinforced concrete and are uninsulated. The building is covered by a pitched roof supported by the concrete slab, which is insulated on its upper side. Some single-storey parts of the school (i.e. the multi-purpose hall) are covered by a flat roof, insulated with extruded polysterole and covered with cement tiles. The external wall structure is of double brick, with a layer of insulation of heavy polystyrene in the middle. Floors are constructed of concrete slab and covered by marble or mosaic. Windows are double glazed with aluminium frames.



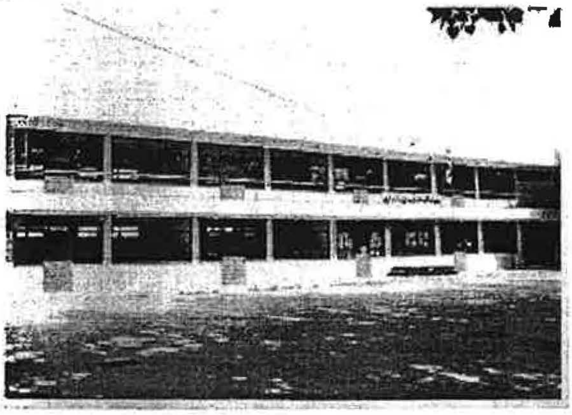
View of the Southeast Elevation

Classrooms are oriented to the North and West. Solar orientation is therefore poor, resulting in increased heating load during the winter and overheating during May, June and September.

Daylighting is adequate, but glare problems occur regularly in the West-facing classrooms during the afternoon shift. Although solar control systems, venetian blinds and curtains are used, they only partially reduce glare and overheating. Natural cross ventilation may be achieved through opening existing windows on opposite walls, but most often many remain closed. There is a conventional central heating system consisting of an oil fired boiler and manually controlled hot water pipework and local radiators. Artificial lighting is achieved by common fluorescent luminaire sets in the classrooms, and by incandescent lamps in auxiliary spaces, corridors, and exterior spaces.

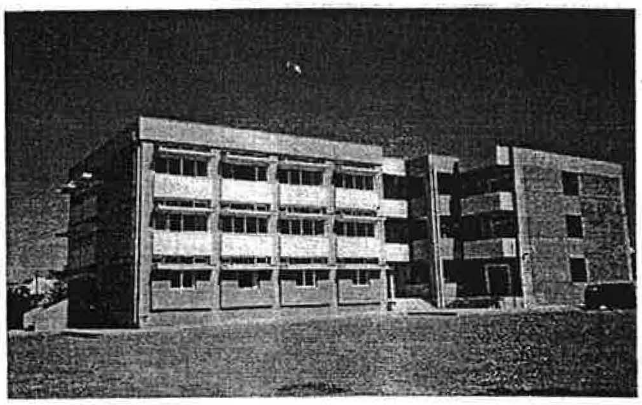
High School of Nea Erythrea, Athens

The school was built in 1975, before the establishment of the Thermal Insulation Regulation by the Organisation of School Buildings (OSK) and is typical of its era. The 2,427 m^2, two-storey building is located in N. Erythrea, a suburb of Athens, which belongs to the second climatic zone of Greece (Zone B). The school operates in one shift, 8:00-13:00. Its rooms are linearly located along an open corridor in two wings. The L-shaped school building, along with the single storey multi purpose hall, form a U-shaped structure embracing the school yard. The school is located on a busy main road. The structural element of the building is reinforced concrete and the external walls are of double brick. Roofs are flat. All exterior building elements are uninsulated. Windows are single glazed on steel frames.



Classrooms face the school yard, one wing facing South and one East. The problems recorded are extreme noise levels inside the classrooms, poor ventilation and air quality, cold during winter, overheating during the warm period (especially in the east wing), and glare. There is a conventional central heating system consisting of an oil fired boiler and manually controlled hot water pipework and local radiators. The system is in poor condition, due to lack of proper maintenance. Artificial lighting is achieved by common fluorescent luminaire sets in the classrooms, and by incandescent lamps in auxiliary spaces, corridors, and exterior spaces. The lighting installation also is in poor condition.

13th Primary School of Chania



The school, constructed in 1994, is located at Chania, Crete, which belongs to the warmest climatic zone (zone A) of Greece. The building occupies 1,949 m^2 and has two storeys. School operation is limited to one morning shift. The school structure is reinforced concrete and bricks. The beams and columns are unplastered on the outside. Even though the building was built after the implementation of the Thermal Insulation Regulation, the building, as reported by on-sight survey, is uninsulated. The floors and roofs are made of cellular slabs 40 cm thick, with expanded polystyrene in the cavities (Zölner] Floor coverings are of mosaic marble. Windows are single glazed on aluminium frames.

Classroom windows face north, south, east, and west, with no shading devices, except by an ove of 80 cm over the windows on all sides. Due to this variation, daylighting and thermal cond vary between classrooms. Overall, glare, inadequate shading and ventilation and overheating a most common problems. There are skylights above the windows and on the opposite walls, allow cross ventilation. Small fans are installed on the external skylights for ventilation. C heating, when needed, is effected by an oil fired boiler and a manually controlled hot water pipe and local radiators. Artificial lighting is achieved by fluorescent luminaire sets in the classrooms by incandescent lamps in auxiliary spaces.

REFURBISHMENT SOLUTIONS

Refurbishment solutions proposed to reduce the energy consumption for heating and lighting, improving at the same time thermal and visual comfort conditions and air quality in all three case studies, are:

- Window frame sealing to reduce infiltration heat losses
- Installation of internal or external louvered blinds for shading and glare reduction, and plantation of trees
- Addition of mechanisms to enable easy operation of existing skylights
- Rational operation, regular maintenance, proper monitoring and thermal insulation of central heating system, i.e. boiler efficiency and comfort measurements, regulation of hot water temperature as well as fuel and water flows and thermal insulation of hot water pipework

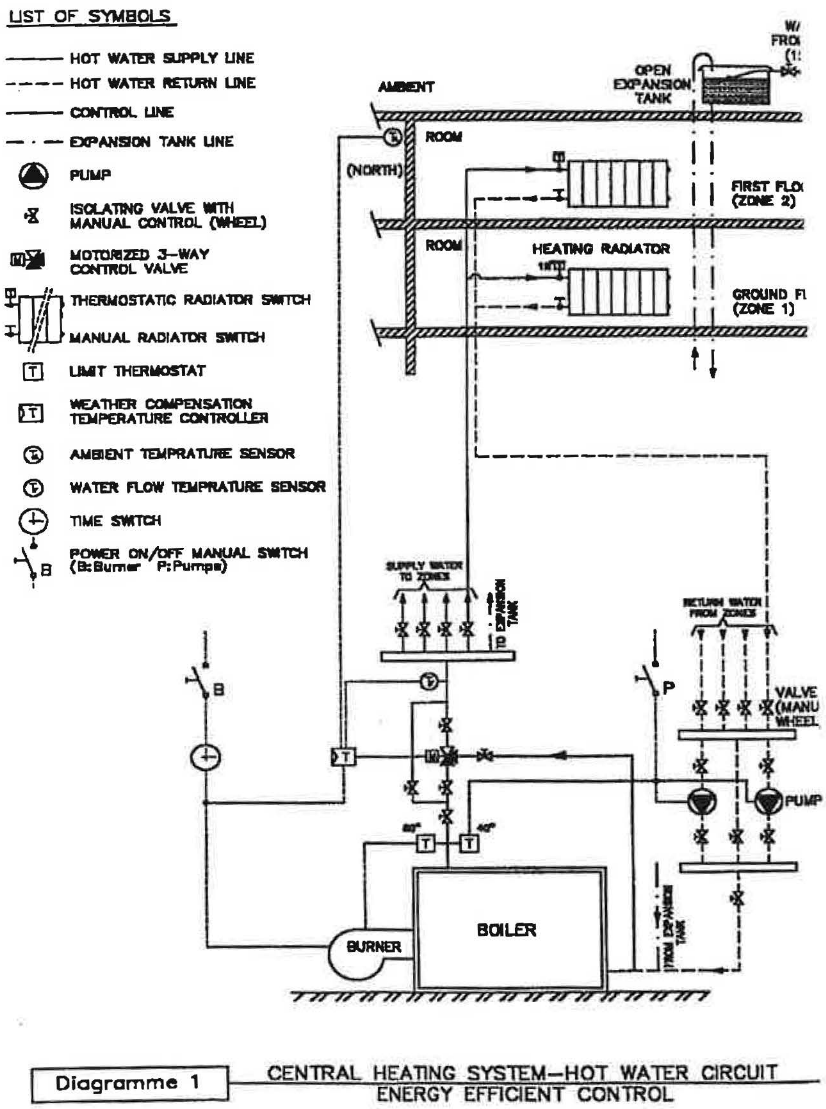


Figure 1. Energy efficient control system

- Installation of a complete weather compensation control system with time and local thermostatic override, i.e. application of an optimiser, a 3-way control valve and timers and thermostatic radiator switches (Figure 1)
- Replacement of incandescent tungsten filament 100W lamps used in common use spaces, with compact, energy saving, long lasting 20W fluorescent lamps
- Replacement of opal luminaire covers with covers having reflector systems
- Installation of local manual switches and dedicated electric circuit to control independently perimeter lighting zones in areas with adequate daylight
- Incorporation of appropriate passive solar systems to preheat the incoming fresh air, and installation of vents, or ducts to distribute the preheated air to the classrooms.

The following solutions are specifically proposed for each one of the three case schools:

23d High School of Thessaloniki

- Transformation of the south-facing corridor of the first floor into a solar space, by replacing the exterior wall by glazing, and enlargement parts of the corridor which protrude over the ground floor. This solution requires replacement of the pitched roofs of the ground floor by flat roofs which may be covered by plants. (Figure 2)
- Installation of thermosyphoning air panels in front of the staircases to provide preheated fresh air into the classrooms. (Figure 2)

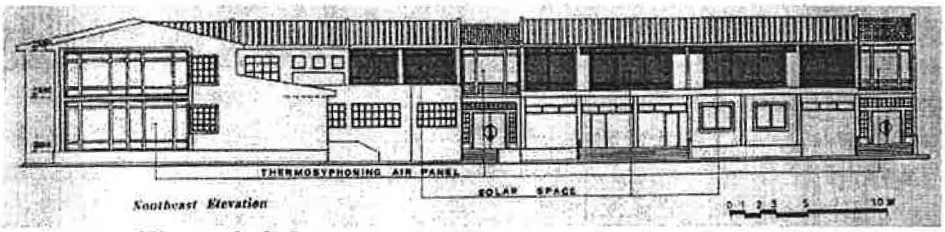


Figure 2. Solar space and thermosyphoning air panels

High School of Nea Erythrea, Athens

- Addition of thermal insulation on roof and walls
- Installation of ceiling fans in the classrooms
- Creation of a closed corridor-sunspace on the main side of the classrooms, to reduce noise, and pre-heat fresh air in the winter time. The fresh air will be drawn through openings at the top of the sunspace, facing the noiseless side of the building, and will be directed towards the classrooms by fans (Figure 3). During the warm period, classroom air will be vented through the openings at the top of the sunspace. Low noise supply and exhaust fans will assist cross ventilation of classrooms during all seasons.

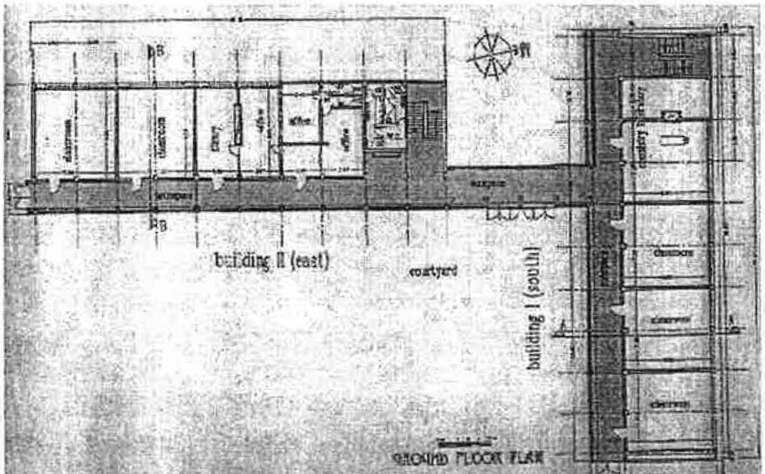


Figure 3. Closed corridor sunspace

- Replacement of the old boiler-burner set with a new one possessing a modular, dual fuel burner and a high efficiency, low exhaust gas temperature boiler.

<u>13th Primary School of Chania, Crete</u>

- Addition of thermal insulation on the roof
- Installation of ceiling fans in the classrooms
- Construction of a sunspace on the south side in front of the school entrance (Figure 4)

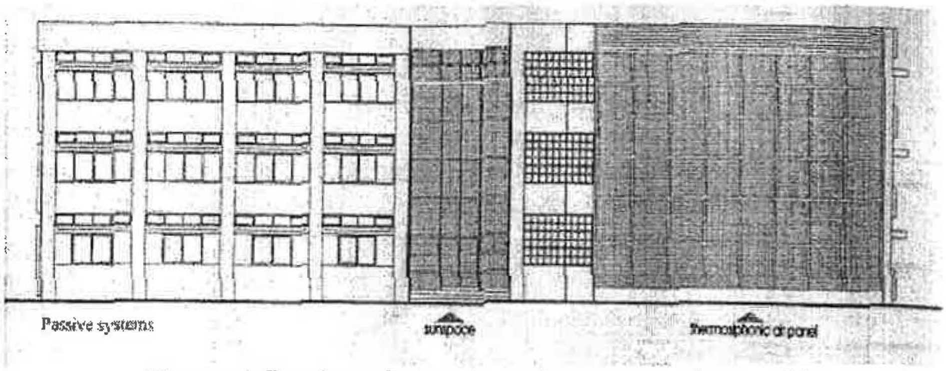


Figure 4. Passive solar systems (sunspace, air panels)

- Incorporation of a thermosyphoning air panel on the south side, on the exterior side of the stairca to provide fresh air to the classrooms on the rear side via ducts. (Figure 4)

ENERGY ANALYSIS

Building energy analysis was performed using the simulation programme SUNCODE PC [2]. Tl results were verified by actual measurements. Various options were analysed in order to assess their contribution to the reduction of the heating and cooling loads and their effect on comfort conditions. The simulations were carried out in two modes. The first was the free running mode of the building that provided an insight into how the building would perform without any heating and cooling system. The assessment of the energy performance of each solution was made in the second mode, by comparing the energy consumed for heating or cooling each existing building, assuming the heatin system operates by thermostatic control, with the energy consumed when a specific technique c combination is applied to the building.

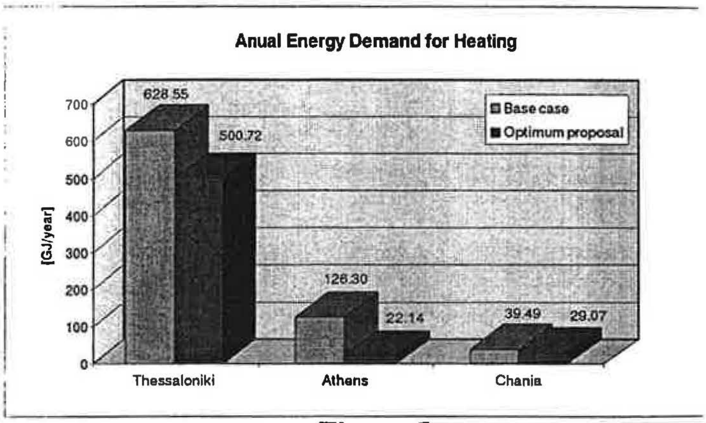


Figure 5.

The assumptions made for the simulations are as follows:

- Schools operate from 1st September to 30th June during week days.
- The average occupancy considered for each classroom is 29 students and a teacher (OSK specifie a maximum number of 30 students).
- For health reasons (according to OSK specifications) the required ventilation rate in eac classroom is 5 ACH during the hours of operation. When the building is unoccupied, 1 ACH i assumed for buildings with new, well preserved aperture frames, and 2 ACH for old and poorl constructed aperture frames.
- Conventional heating and cooling systems are set to operate only during schooling hours and wit thermostat settings at 18 ^oC and 27 ^oC for the heating and the cooling period respectively.
- During the cooling period in order to estimate the impact of shading and natural ventilation on th cooling load the following assumptions have been made which are rather conservative especiall

with regards to shading. It has been considered that windows are 50% shaded, in order to balance daylighting requirements in the classroom. The above is the average value given in [3] for different shading types - such as venetian blinds vertical or horizontal and light colour curtains.

- Natural ventilation has been estimated to 10 ACH during the ventilation period (a rate which has been considered conservative, easily achieved and not too high to cause disruption in the classrooms). Various scenaria have been simulated in order to reach the optimum ventilation schedule.

The climatic data used in the simulations were hourly values of the typical day of each month. The ambient temperature and relative humidity, and wind speed have been taken from the Greek National Meteorological Service (E.M.Y.) [4], whilst the solar radiation values have been calculated using the software Helios Ver. 2.01 [5].

The annual energy demand for heating each building, before and after the individual or combined application of technically optimum refurbishment options to its envelope, is presented in Figure 5. Furthermore, an analysis, based on relevant bibliography [6], was carried out to consider the increase of mean heating efficiency of the existing conventional central heating system, due to the application of automatic controls, efficient fuel burning and heat generation equipment as well as improved pipework and boiler insulation, rational operation and improved maintenance. The mean efficiency of the heating system was assumed to be 65% before refurbishment, considering the existing system quality and operating conditions. The analysis resulted in the determination of the annual fuel consumption and the required central heating system capacity, based on the building thermal simulation and on in site energy survey data.

The measures proposed for space heating will have the following additional effects on the thermal comfort conditions inside the classrooms :

- Reduction of infiltration heat losses will result in elimination of discomfort caused by cold air currents at the head level of the pupils
- Preheating the incoming air and controlling the air supply by fans at the required rate, will result in improved air quality, and in reduced heat losses caused by uncontrolled ad hoc ventilation from window opening during brakes.
- Roof and wall insulation will result in reduction of radiative heat exchanges among the pupils and exterior walls and ceiling, increasing comfort sensation.

An energy analysis based on field survey data and daylight assessment was finally effected for the estimation of electricity consumption for lighting before and after the proposed solutions. The analysis took into account the installed electric power of incadescent and fluorescent lighting per unit floor area and assumptions regarding the yearly operating time. The energy effect of refurbishment solutions for lighting was estimated on the basis of appropriate reference [7]

ECONOMIC ASSESSMENT

The economic assessment was performed for all solutions proposed for energy efficient space heating and lighting. The assessment was elaborated using Discounted Cash Flow analysis (DCF) over the life cycle of each solution . The economic value from the end user, i.e. school municipalities, point of view was expressed in terms of the Discounted Pay Back period (DPB) calculated from equation (1) :

$$K = \sum_{t=1}^{(DPB)} [F_t / (1+d)^t] \qquad (1)$$

In equation (1), K is the capital investment differential cost, F_t is the annual operational economic benefit for the end-user because of energy saving, in year t, and d is the discount rate ($0<d<1$). A discount rate d=10%, net of inflation was assumed for the end-user during 1995. The capital investment cost of each particular energy saving solution is recuperated through the annual energy savings which occur as well as the avoided capital cost of the conventional central heating and artificial lighting equipment displaced because of the reduction of peak heating load and electrical load for lighting. The annual operational economic benefits for heating and lighting are calculated in relation to the corresponding fuel unit cost and electricity utility tarrifs. Characteristic DPB values are presented for specific viable energy saving proposals and for all three case studies, in Figure 6 for the case school in Athens.

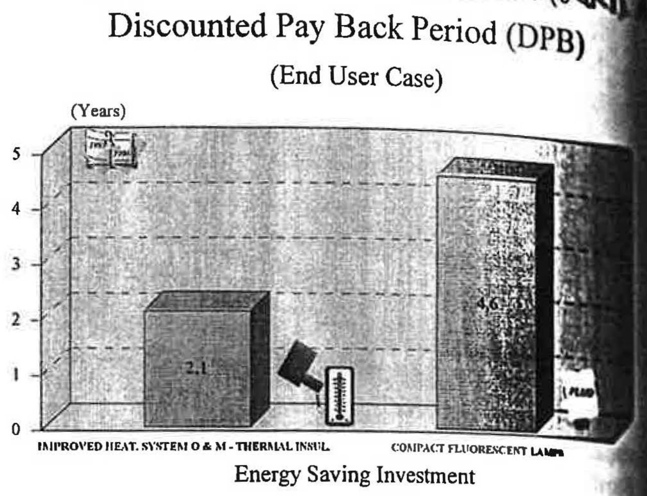


Figure 6.

The benefits to the Greek national economy were evaluated through the life cycle discounting of all costs and benefits of the energy saving options proposed, i.e. through the calculation of the relevant Net Present Value (NPV), based on which central governmental authorities may decide on specific actions to enhance the introduction of these options in schools. NPV is calculated from equation (2):

$$(NPV) = \sum_{t=1}^{N} [F_{tNE} / (1+d_{NE})^t] - K_{NE} \qquad (2)$$

In equation (2), N is the lifetime of the energy saving option, K_{NE} is the capital investment differential cost, F_t is the annual operational economic benefit for the national economy because of energy saving, in year t, and d_{NE} is the relevant discount rate ($0<d_{NE}<1$). A net discount rate d_{NE}=3%, was assumed during 1995. National economy costs and benefits take into account the domestic added value of the proposed energy saving options, the foreign capital savings for importing fuel oil and the exploitation cost of local lignite. Two types of fuel oil are considered, the one for space heating and the other for diesel engine power station operation in remote areas not connected to the national grid (case school in Chania). Lignite is burned in base power stations connected to the national grid. A shadow price of 25% on the price of US$ 170 / m^3 of imported oil was considered and domestic added values of 80% and 50% were assumed for heating and lighting equipment respectively. The cost of diesel fired power stations was taken equal to 50 Drs/kWh_e. Characteristic NPV values are presented for specific viable energy saving proposals and for all three case studies, in Figure 7, for the case school in Thessaloniki.

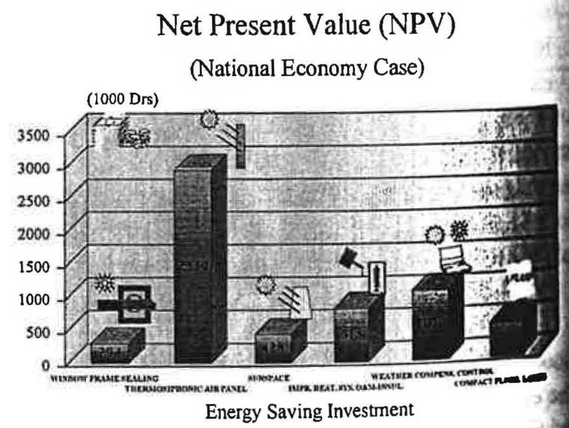


Figure 7.

ENVIRONMENTAL ASSESSMENT

The contribution of the proposed energy saving options to the reduction of environmental pollution and of indirect costs to sustain accepted environmental quality was detected through the determination of the positive impact of these options to the CO_2 and SO_2 emissions. (Figure 8 for the case school in Thessaloniki). The following were assumed :

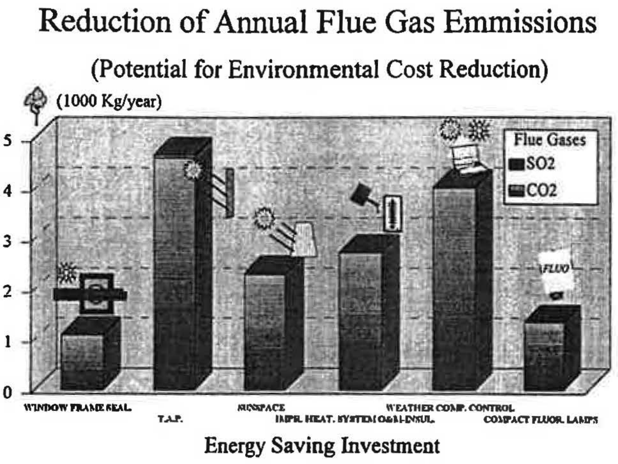


Figure 8.

- 1 kg of diesel oil produces by its burning 3.1 kg of CO_2 and 0.02 kg of SO_2
- 1 kg of lignite produces by its burning 0.8 kg of CO_2 and 0.004 kg of SO_2
- 1 electric kWh produced from a diesel oil fired power plant requires 2.2 kWh = 7.9 MJ of fuel thermal energy input, i.e. 0.2 kg of diesel oil producing 0.6 kg of CO_2 and 0.004 kg of SO_2 (case in Chania)
- 1 electric kWh produced from a lignite fired power plant requires 3 kWh = 10.8 MJ of fuel thermal energy input, i.e. 1.6 kg of lignite producing 1.3 kg of CO_2 and 0.007 kg of SO_2 (case in Athens and Thessaloniki)

CONCLUSIONS

The overall energy, economic and environmental assessment of the refurbishment proposals in the three greek schools results to the following most appropriate solutions :

- Thermal insulation and improved operation and maintenance of the existing central heating system for all three schools
- Compact electronic fluorescent lamps replacing incadescent filament lamps for all three schools
- Application of complete weather compensation control with a 3-way valve circuit, time and local thermostatic control directly for the budget of the school in Thessaloniki and for the other two schools after state support
- Window frame and envelope crack sealing for the school in Thessaloniki after state support
- Thermosyphoning air panel for the school in Thessaloniki after state support
- New boiler-dual fuel burner set for the school in Athens after state support
- Corridor sunspace for the school in Athens after state support

The case energy refurbishment of three schools has demonstrated that several passive and low energy solutions, even when expensive for the end-user, are viable when viewed at a national economy scale and taking into account the associated environmental benefits. State support should focus on the financing of the above mentioned solutions and generally on the supply of expert aid in energy management activities in cooperation with municipalities (designation of school energy manager, special energy budget, specification of relevant activities).

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REFERENCES

1. Tzanakaki, E. editor, Technical and Economical Assessment of the Refurbishment of School Buildings for Energy Efficiency and Improvement of Thermal and Visual Comfort Conditions, EU/DG XVII SAVE Project 4.1031/93-76, CRES, 1995
2. Suncode-PC, Building Load Simulation programme User's' Manual, Ecotope Inc., Seattle, Washington, 1985.
3. ASHRAE HANDBOOK, 1981 Fundamentals.
4. Karras G., Climatic Data for thirty Cities, Report compiled for CRES, CRES 1991.
5. Helios 2.01 "Solar Radiation Modelling Package", Users' Guide, Lamda Technical Ltd., Athens 1989.
6. Tsigas E., Energy Conservation through interventions to HVAC systems, CRES 1994
7. Energy Efficient Lighting in Buildings, CEC/DGXVII THERMIE Maxibrochure-R.U.E. Series, BRECSU 1992