Energy renovation of office buildings in Greece – Potentials based on case studies

Chris J. Koinakis, John K. Sakelaris

***Abstract*—**
The energy renovation and the potentials of the energy savings in two office buildings in Greece are examined in this paper, within the frames of a renovation project for some existing office buildings of the public sector. For this reason energy audits and simulations were performed. Significant energy savings were achieved in both cases. The most effective measures proved to be the energy efficient windows, the solar shading and the natural ventilation strategies, the increase of the insulation of the roof and the external shell, the installation of highly efficient HVAC systems and the upgrading of the artificial lighting. The energy savings could decrease the problems of the increased ventilation that proved to be necessary in the lounge areas and also could decrease the problems of high internal gains due to the new extensive IT equipment. There are potentials for adequate and flexible energy management if a central master plan is implemented for a targeted office building stock of the public sector in Greece.

***Keywords*—** Energy performance, Energy saving, Office buildings, Renovation project, Greece, Trends, Potentials, HVAC, Lighting, IT equipment.

I. Introduction

The office buildings energy consumption is among the highest of the building sector in Greece, after only the hospital buildings. Additionally, the internal gains are furthermore increased during renovation projects, due to the electrical equipment, especially after the recent IT equipment renovation. The above mentioned phenomena combined with the increased thermal comfort demands of the average office building used, increased the total number of the air-conditioned area of buildings at a total of at least 1200 million s.m (Bluyssen et al. 1996), (Wittchen et al. 2002), (Wong et al. 2008).

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In this paper the the potentials of energy savings decrease in two office buildings in northern Greece are examined, within the frames of a renovation project in office buildings of the public sector. These buildings were selected as a specimen of office building in Greece, (Koinakis 2000-6).
In the Northern Europe, according to relevant energy studies in common-type office buildings, the annual energy consumption varies from 270 to 350 kWh/m2. In the United Kingdom the mean average consumption in low energy office buildings is 131 kWh/m2, compared to 440 kWh/m2 in common office buildings. In France, according to a relevant study, the buildings were categorized as urban and suburban-rural and the mean annual energy consumptions were 165 and 145 kWh/m2 respectively, as a result of renovation trends and of the increased cooling demands. In a relevant study in Athens in the 1990s the mean annual energy consumption was found 187 kWh/m2, 13% of which were cooling demands.
In the energy study of the examined buildings the general directives of energy auditing in E.U. office buildings were implemented, taking also into consideration the relevant office building program, whenever existed. The simulation were performed implementing the combined use of thermal simulation software Suncode and the ventilation and air contaminant code of COMIS.

II. Basic Principles and Equations of the Implemented Air Flow and Thermal Nodal Modeling

2.1. Air flow modeling

Air flow through the rooms of a building originates from pressure distribution around and within the building itself. Pressure distribution is due to the combined actions of wind, thermal buoyancy (stack effect) and mechanical ventilation - if it exists. Due to the turbulence characteristic of the wind flow in the lower layers of the atmosphere, the pressure field driven by the wind on building surfaces is always unsteady and difficult to predict and simulate. Differential pressure due to the stack effect depends on density field and on the mechanical ventilation (Grosso 1994), (Feustel 1996).

Wind flows produce a velocity and pressure field around buildings. The relationship, for free stream flow, between velocity and related pressure at different locations of the flow field can be obtained from Bernoulli's equation. Assuming constant density along a streamline at a given height Bernoulli's equation can be simplified thus:

$$P_{stat} + \frac{1}{2}\rho \bar{v}^{2} = \text{constant} \quad (1)$$

The wind velocity profile is calculated by a power law expression.

$$\frac{v(z)}{v(z_{ref})} = \left\{ \frac{z}{z_{ref}} \right\}^{\alpha} \quad (2)$$

The value of the exponent a increases with the increasing roughness of the solid boundary. The wind pressure distribution on the building envelope is described by dimensionless pressure coefficients - the ratio of the surface dynamic pressure to the dynamic pressure in the undisturbed flow pattern measured at a reference height. The pressure coefficient Cp at point k(x,y,z), with reference dynamic pressure P_{dyn} related at height z_{ref}, for a given wind direction φ can be described by:

$$Cp_k(z_{ref}, j) = \frac{P_k - P_0(z)}{P_{dyn}(z_{ref})} \quad (3)$$

where:

$$P_{dyn}(z_{ref}) = \frac{1}{2}\rho_0 v^2(z_{ref}) \quad (4)$$

The pressure coefficients of the under examination building are calculated by implementing a parametrical calculation algorithm taking into account climatic, building and environmental parameters (Allen 1984), (Grosso 1994). The results were compared with wind test studies in the bibliography for similar buildings (Kendrick 1993), (Palmiter et al 1991), (Bluyssen et al 1996), (Grosso 1994), (Wittchen et al 2002).

The effect of thermal buoyancy or the stack effect is the other natural phenomenon driving differential pressure in a building. It is due to density differences between inside and outside air or between two zones of a building. The density is mainly a function of temperature and the moisture content of air. The local pressure difference between two points Z_i and Z_j, in the two zones, if M and N are two zones on the opposite sides of a leakage is given by:

$$P_i - P_j = P_m - P_n \, P_s \quad (5)$$

where P_s takes the stack effect into account:

$$P_s = \rho_m g (Z_m - Z_i) - \rho_n g (Z_n - Z_j) \quad (6)$$

Z_m , P_m , T_m , ρ_m , Z_n , P_n , T_n , ρ_m are respectively the height, pressure, air pressure and air density at the reference points.

Natural ventilation phenomena in buildings could be categorized mainly as flow through cracks and flow through large openings. The influence of HVAC systems should also be calculated.

Simulation of the air leakage characteristics of cracks under real conditions, based on the exponential power law, takes the general form of:

$$Q = C_s \, \nu^{1-2n} \rho^{-n} (\Delta P)^{n} \quad (7)$$

Air mass flow Q, is described here as a function of pressure difference ΔP. The coefficient C depends on the crack form (duct shape). The flow regime (laminar, transitive or turbulent), the type and geometry of the crack and the temperature of the air in the cracks are also taken into account (Feustel 1996), (van der Maas 1992), (Vandele et al 1989).

The flow through large openings is simulated to fit easily into the network definition and to model the phenomena that influence the behavior of large openings. The main assumptions in the COMIS model are: a) steady flow, in viscid and incompressible fluid; b) linear density stratification on both sides of the opening; c) turbulence effects represented by an equivalent pressure difference profile, and d) effects of reduction of the effective area of the aperture represented by a single coefficient. A general description of the problem to be solved is given in Fig. 1.

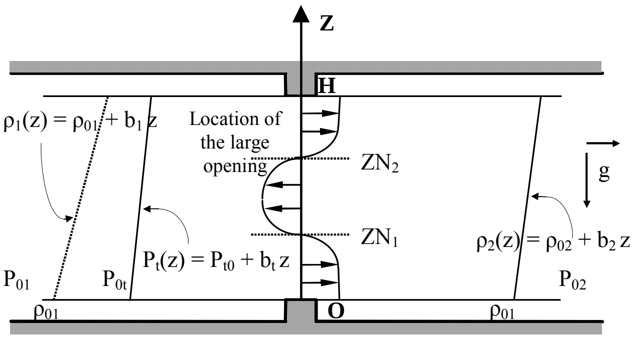


Fig. 1. General problem of gravitational flow through a large vertical opening (based on Vandele et al 1989).

On each side of the opening, linear density stratification is assumed:

$$\rho_i(z) = \rho_{0\,i} + b_i \, z \quad (8)$$

and a linear pressure difference simulating the effect of turbulence is introduced:

$$\Delta P_t = P_{t0} + b_t \, z \quad (9)$$

The airflows moving in both ways through the opening are expressed as follows, after integrations in the intervals defined by the physical limits (see Fig 1) of the opening and the position of the neutral planes:

$$\dot{m}_{0,z1} = Cd \; \theta \int_{z=0}^{z=z1} \rho \; v(z) \; W \; dz \quad (10)$$

$$\dot{m}_{z1,z2} = Cd \; \theta \int_{z=z1}^{z=z2} \rho \; v(z) W \; dz \quad (11)$$

$$\dot{m}_{z2,H} = Cd \; \theta \int_{z=z2}^{z=H} \rho \; v(z) \; W \; dz \quad (12)$$

From the preceding equation it appears that the flow through a large opening is directly proportional to an empirical discharge coefficient *Cd*, taking into account the contraction of the flow due to the existence of the opening. Theoretically it depends on the fluid and the local flow characteristics caused by the shape of the opening. Its value varies from 0.61 for sharp-edged orifices to 0.98 for trumpet-shaped nozzles. Generally, these integrals have no analytical solutions and they have to be computed by numerical means (e.g. a classic Simpson integration). This numerical solution is general but it is also time-consuming and is reserved for more general case.

Further analysis of the problem may be found in the bibliography (Kendrick 1993), (Feustel 1996).
Nodal natural ventilation programs like the COMIS model which is implemented in this work establish the infiltration and ventilation rates in a building by solving of a non-linear system of equations that represents a network. An iterative method can be used in which a linear system of equations is solved at each step of the process. The network consists of pressure nodes and links. A mass flow balance must exist at each node, as described by the following flow balance equation:

$$f(P) = \sum_i \frac{dm_i}{dt} = 0 \tag{13}$$

and in vector form for all nodes:

$$\mathbf{f}(\mathbf{P}) = 0 \tag{14}$$

An appropriate function describes the flow rate as a function of pressure difference for each link. Non-linear expressions of the following type are predominant; for a better understanding we here disregard the temperature correction factor K. introduced in

$$\dot{m} = C_{\dot{m}} (\Delta P)^n \text{, where } 0.5 \le n \le 1.0 \tag{15}$$

Equation (15) is obviously a non-linear system of equations.
The Newton-Raphson method finds the next approximation in the multi-dimensional case through the following iteration function h(P):

$$\mathbf{P_{n+1}} = \mathbf{P_n} - \frac{\mathbf{f}(\mathbf{P_n})}{\mathbf{J}(\mathbf{P_n})} \tag{16}$$

where $\mathbf{J}(\mathbf{P_n})$ is the Jacobian matrix. The Jacobian matrix is obviously similar to $f'(P_n)$. The matrix consists of the partial derivatives of all the flow balance equations f regarding all pressures P

2.2. Thermal modeling

A nodal thermal model like the Suncode which is implemented here has similar structure to the nodal multizone air infiltration model. It is based on the concept of the thermal zone, which might be a room or a total of rooms or a whole building under a single zone temperature node. This is a conductance weighted average of all temperatures which affect the zone. Each zone has independent solar inputs, independent HVAC systems and natural ventilation conditions (Palmiter et al 1991), (van der Maas 1990), (Vandele 1989). Zones may be connected by walls which are connected by a constant heat transfer coefficient to the central zone node. The heat transfer coefficient includes both convective and radiative heat transfer. In some circumstances the central node temperature may differ significantly from the true “air” temperature. Nevertheless, with proper calculation of the combined zone surface coefficients, the resulting error is comparable to that produced by differences in radiation transfer resulting from the detailed modeling of furniture in the zone. The central zone temperature T could be referred to as zone “air” temperature. Ventilation rates are set separately for each zone as calculated from the nodal ventilation model, where pressure zones are identical to the thermal model zones. No vertical stratification of flows is implemented in the thermal model. For each 1h time step new node temperatures are calculated for each mass wall defined.

The energy balance equation defining the zone air temperature, T, can be expressed as:

$$\text{Qwall} + \text{Qzone} + \text{Qwindow} + \text{Qamb} + \text{Qgrd} + \text{Qinf} + \text{Qsolzon} + \text{Qappli} + \text{Qfan} + \text{Qheat} - \text{Qvent} - \text{Q cool} = 0 \tag{17}$$

where:

Qwall = energy flow between zone and enclosing mass walls;
Qzone = energy flow between zones through explicitly defined interzone loss coefficients or through massless walls between zones;
Qwindow = energy flow through windows;
Qamp = energy flow to ambient air through explicitly defined loss coefficients to ambient or through massless walls between zone and ambient;
Qgrd = energy flow to user-specified “ground” node through explicitly defined loss coefficients to ground or through massless walls between zone and ground;
Qinf = energy flow due to air infiltration and ventilation;
Qsolzon = total solar heat gain to zone;
Qappli = user-defined appliance gain;
Qfan = energy flow between zones by fans;
Qheat = heating energy supplied to zone;
Qvent = energy removed from zone by venting;
Qcool = energy removed from zone by cooling.

The above equation is simplified by removing the addendums referring to special passive solar systems, which are not included in the building under examination.
The thermal network model contains only nodes with heat capacity in the interior of the wall. The governing equation for these internal nodes is derived from an instantaneous heat balance on the node. The rate of heat storage equals the rate of heat gain from the node to the left, plus the rate of heat gain from the node on the right. It is expressed mathematically as follows:

$$C \cdot \frac{dT}{dt} = HL \cdot (TL - T) + HR \cdot (TR - T) \tag{18}$$

where:

T = middle node temperature.
TL = left node temperature.
TR = right node temperature.
HL = thermal conductance to left node.
HR = thermal conductance to right node.
C = thermal capacitance of middle node.
$\frac{\mathrm{dT}}{\mathrm{dt}}$ = time derivative of middle node temperature.

The differential equations (one for each node) are solved by using explicit finite differences or Euler integration. The new temperature at the end of a time step is approximated as:

$$T' = T + D \cdot \left(\frac{dT}{dt}\right) \tag{19}$$

where:

T' = new node temperature at the end of time step

T = old node temperature

D = length of time step (1 h).

The results in a set of independent equations for the new node temperatures, each of which have the form:

$$T' = \left(1 - D \cdot \frac{HL}{C} - D \cdot \frac{HR}{C}\right) \cdot T + D \cdot \frac{HL}{C} \cdot TL + D \frac{HR}{C} \cdot TR \tag{20}$$

The second law of thermodynamics, as well as the mathematical stability of explicit solution, requires that the first term in parenthesis should not be negative.

Energy flow, *Qinf,* due to infiltration and ventilation is calculated as follows:

$$Qinf = UAinf \cdot (Tamb - T) \tag{21}$$

where:

$Tamb$ = Ambient air temperature.

T = zone air temperature.

$Uainf$ = infiltration equivalent conductance value.

where:

$$UAinf = vol \cdot Cair \cdot Pair \cdot e^{a \cdot elev} \cdot ACH \tag{22}$$

where:

vol = zone air volume in m^3.

$Cair$ = air specific heat = 1.00418 KJ / kg·C.

$Pair$ = air density at sea level = 1.20138 kg/m^3.

$elev$ = station elevation in m.

a = coefficient derived from exponential curve fit = -1.219755·10^{-4} / m.

ACH = infiltration and ventilation air change rate in h^{-1}.

III. COMBINED THERMAL AND VENTILATION MODELING

Two basic cases of the coupling of a thermal model with a ventilation model may be distinguished:

- The zone temperatures are first calculated by the thermal model using predefined ventilation rates as inputs and then the zone flows are recalculated by the ventilation model using the calculated temperatures as inputs.
- The flows are first calculated by the ventilation model using predefined temperatures as inputs and then the zone temperatures are recalculated by the thermal model using the calculated flows as inputs.

Thermodynamic balance needs to be established in either case of coupling, whether the temperatures are different in the two models (2nd case), or the ventilation flows are different (1st case). In this work the thermal model (COMIS) and the ventilation model (Suncode) are two autonomous programs that are executed sequentially at 1h time-step (sequential coupling). There are, therefore, individual input and output files for the interconnection of the models, so the sequential coupling occurs at each time step. The coupling procedure implemented is presented in Fig. 2 and 3.

If the procedure is not implemented carefully, sequential coupling could affect the thermodynamic integrity of the system and therefore the zone temperatures and the thermal flows through building elements could be erroneous. The coupling was checked and validated, performing real case measurements, as described in the next paragraph.

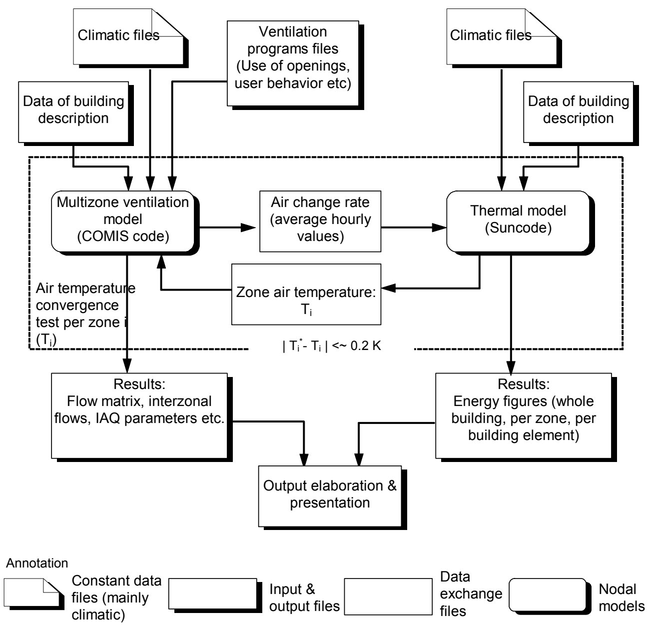


Fig. 2. The introduced procedure of thermal and infiltration coupling.

The integrity of the final results depends greatly on the pattern of changes in the boundary conditions and on the simulation time step. The solution of the nodal network model is based on mass balance as follows: during each time step, the mass transport problem is simulated by a steady flow of incompressible fluid (air), through the flow links (cracks or large openings) which form the flow path network of the building. The steady flow mentioned above could be unidirectional, bidirectional, or a flow through cracks, depending on the ventilation phenomena (single-sided or cross ventilation, infiltration, flow through ducts), implementing the appropriate model in each case. This network operates under certain boundary conditions, defined from climatic data, wind pressures on the building's envelope, as well as temperatures and thermal flows of building elements. The problem therefore focuses on calculating the mass flows through flow links which connect the nodes (zones) of the network that stand for the zone pressures, which are the unknown quantities of the problem. The solution is achieved by implementing an iteration method for mass balance equations and the unknown nodal pressures are iteratively approximated.

Each node has a specific reference height and a specific air temperature, depending on the boundary conditions in the zone. The reference height and the temperature are then used for calculating the flows due to buoyancy (stack effect), which are of great importance.

The flow chart in Fig. 3 shows that in the case of sequential coupling during a time step, air flows (in fact mass flows) are calculated on the assumption that the air temperature is uniform of each zone (T_i^*) in the previous time step. During the first passage of a specific time step the zone air temperature equals T_i^*, where i is the variable that defines the number of iterations performed in the specific time step. Therefore, in each iteration the relation $(T_i^* + T_i)/2$ is used which means sequential replacements with a relaxation factor 0.5.

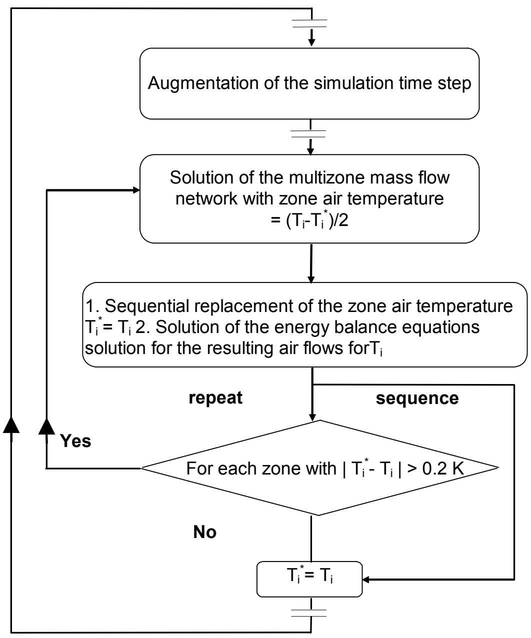


Fig. 3. Flow chart of sequential coupling procedure.

IV. ENERGY SAVING STRATEGIES

The first data collection and process began at the primary energy audit, where the general building data were collected, based on the building construction studies and plans and on questionnaires. This phase was followed by the examination of the energy consumption strategies, implementation also energy simulations. The demands of the overall construction development program of the public offices (roll out) were also taken into account, as well as the need to have as many office buildings operating as possible. The main outcomes of this "phase –A" procedure, are the following:

- The cooling demands will be increased after renovation projects, in certain cases even in spring and autumn, due to the increased IT equipment, the decrease of conductivity thermal losses from the building shell and in some cases due to overheating problems.
- Emphasis should be given to the Indoor Environmental Quality (IEQ), especially increasing air changes per hour, avoiding air drafts near working areas due to natural or mechanical ventilation. In certain cases serious complains and health problems were reported related to these air drafts. Odor problems and lack of fresh air were also reported near the lounge areas during peak hours.
- Some advisable energy measures, unfortunately, could not been implemented due to technical and economical reasons. For example external shading and complete thermal insulation of the entire building shell was not possible to be implemented in short-term development program, due to budget and roll out problems. It was therefore essential to be shifted to the mid-term program.
- Low level of the artificial lighting, even below of 300 lux/m2 was found in some cases, as well as glaring problems due to uncontrolled day lighting especially in IT working areas.

The above-mentioned outcomes lead to energy consumption strategies adapted to the specific building use. The main points of these strategies are referred in brief:

- The increased cooling demands were faced at first by hybrid and mechanical ventilation systems. Night cooling was implemented through certain large openings. Then they were installed split VRV air conditioning units BMS controlled.
- The hybrid and mechanical ventilation helps to achieve adequate indoor air quality in the office spaces, combined with mixing of indoors and outdoors air when necessary. Air duct grids were adjust to avoid air draft problems, near the working areas and to insure uniform air mix.

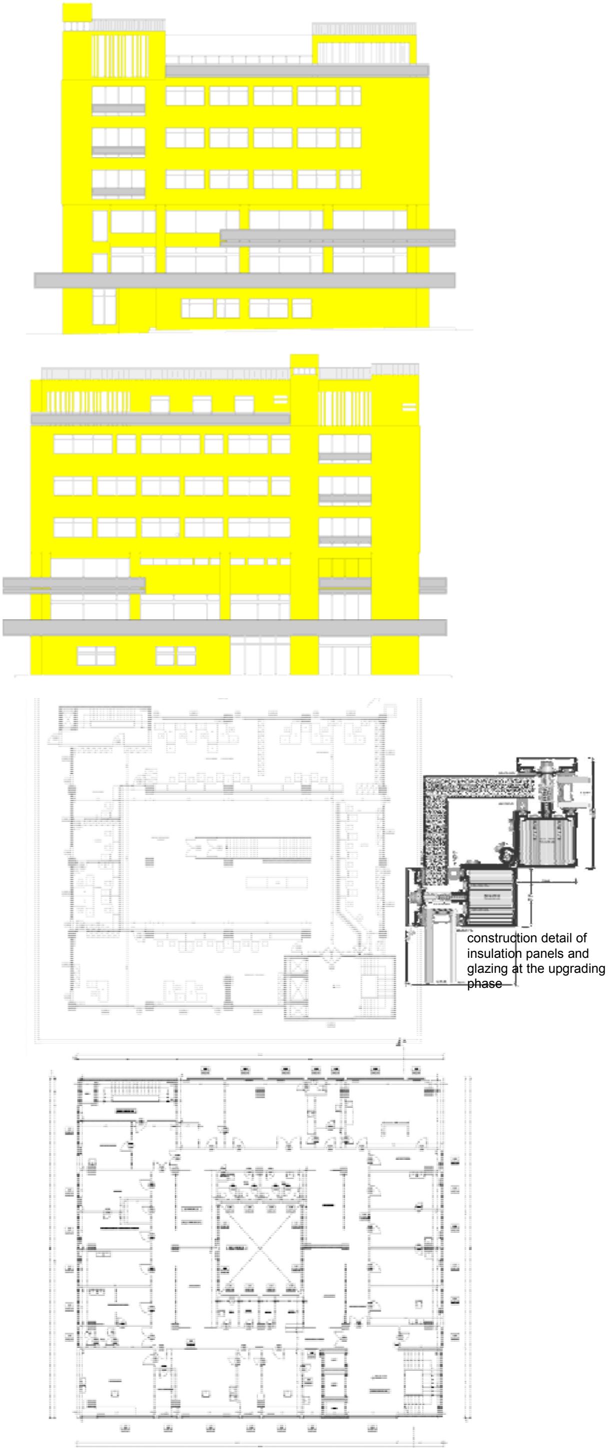
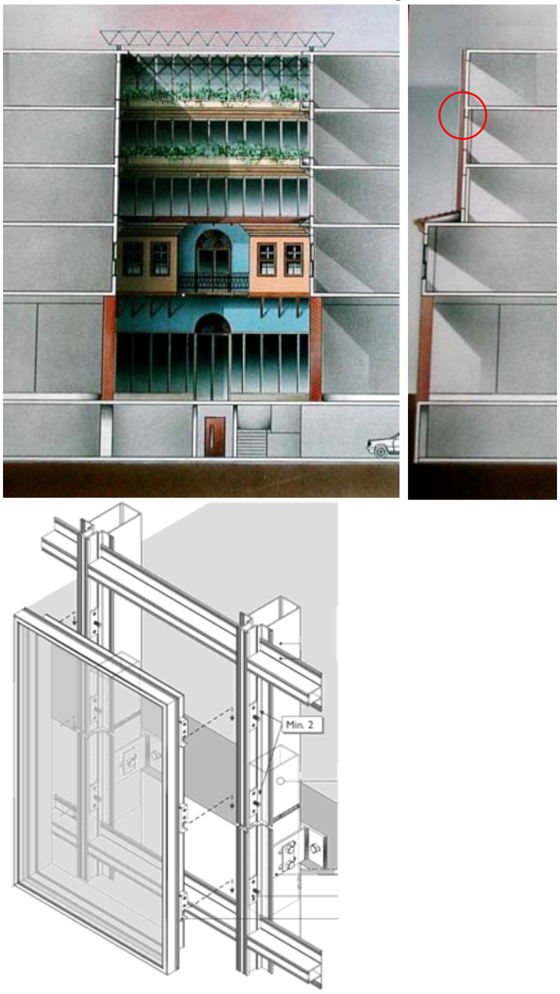
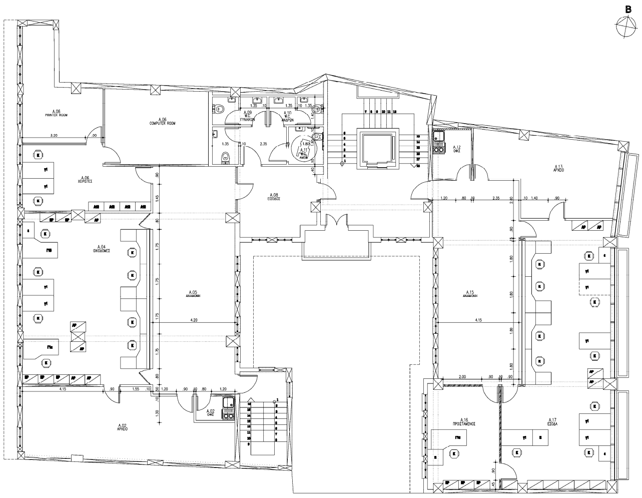


Fig. 4. The office building in Thessaloniki. Typical plan views, facades and construction details of the building shell during

- The advisable energy measures that could not implemented were either replaced by close-by solutions, or programmed for mid-term implementation. Some of the insulation works of the buildings envelope were programmed for the near future.
- The low level of the artificial lighting was faced implementing low consumption fluorescence tubes achieving values of 500 lux/m2. The glaring problems were solved using venetian blinds and in certain cases light selves in windows.



D 1: construction detail of curtain wall during the upgrading phase



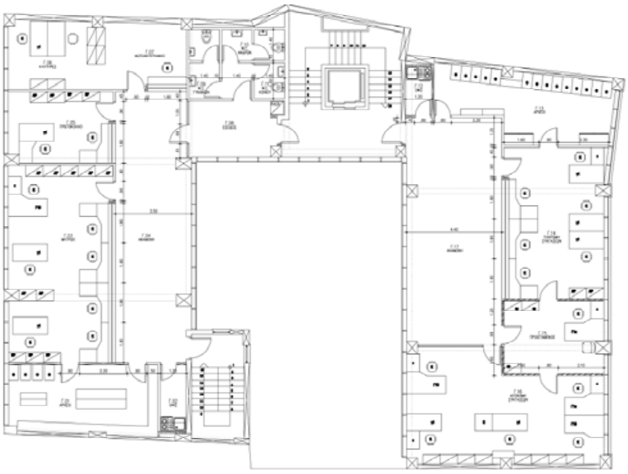


Fig. 5. The office building in Kozani. Typical plan views,

V. CONDITIONS BEFORE THE RENOVATION

The initial (pre-upgrading) conditions of the buildings are presented in table 1, based on the in-situ audits, on the construction studies and on the annual fuel and electricity bills. The indoor environment conditions of the initial conditions were classified according to questionnaires in three categories: adequate, acceptable and non-acceptable conditions.

Table 1. Initial conditions of the buildings in the case studies

Year of construction	1967	2000
Location	Thessaloniki	Kozani
Use	Office and medical laboratories	Offices
Heated/non heated area in m2	7120/6210	4480 /3900
Number of floors	7+basement	5+basement
Shell . roof insulation	- / inadequate insulation in the roof	Greek insulation code of 1978
External openings	Single glazing and wooden non insulating and non weatherproof windows	Double insulating glazing and aluminum weatherproof windows
Shading devices	Only internal shading in 15% of the required area	None
Heating system	Oil boiler and calorifiers	Tele-heating and auxiliary oil boiler and fan coils.
Heating period (months per year / oper. hours per day)	5,5 m / 16 h	7 m / 9 h
Annual specific heat consumption	190 KWh/m^2	160 KWh/m^2
Thermal comfort during winter	Non acceptable	Acceptable
Cooling system	Air duct water-cooled A/C system. A few isolated A/C split units	No cooling
Thermal comfort during summer	Non acceptable	Acceptable
Cooling period (months per year / oper. hours per day)	4 m / 12 h	3 m / 10 h
Ventilation	Mechanical ventilation in isolated rooms of special use (microbiological laboratories, WCs etc)	Mechanical ventilation in WCs only.
Use of hot water	Isolated quick-heat boilers	Isolated quick-heat boilers
Annual specific electricity consumption	143 KWh/m^2	95 KWh/m^2
Artificial lighting	Old technology incandescence lamps, and fluorescent lamps	New technology fluorescent lamps of medium efficiency.
Elevators	Old semi-automatic, non efficient	New automatic, efficient.
Use of electrical and IT equipment	High (IT equipment, computer room etc.). Very high in some locations (special medical equipment).	High (IT equipment, computer room etc.).

VI. ENERGY RENOVATION STRATEGIES

6.1 Heating

The audits and the energy simulations proved that the most effective energy efficiency measure is the replacement of the external windows, with new double-glazing weatherproof windows and special openings at the top for natural ventilation in selected areas and hours. Two window types were selected with thermal loss coefficient of 2,7 and 1,8 W/m2K for the buildings in Thessaloniki and the Kozani respectively. The heating demand loads are furthermore decreased when thermostats are placed in the inner spaces. The decrease is 2,5% and 3,5% for the buildings in Thessaloniki and the Kozani respectively. The uncontrolled ventilation was significantly reduced due to the weatherproof windows and the mechanical and hybrid ventilation. Solutions leading to lower ventilation rates were rejected due to poor IEQ, especially at the lounge areas. In there areas adjustable extensive ventilation was implemented to achieve 6 ach. The use of recuperation of heat could be implemented in these cases, but it is planned for the near future due to technical reasons.

A BMS system was used to control the air-conditioning VRV system, especially for the summer period. According to the simulations, a 10C decrease of the thermostat temperature could decrease the heating demands at 3,5%

6.2 Cooling

The decrease of the cooling demands during the summer is achieved in the examined buildings, mainly -in order of importance- by a) movable shading (venetian blinds), b) hybrid night cooling and c) by high efficient air-conditioning system. In the building of Thessaloniki the cooling demand is decreased by 37%, because it is exposed to sun in all its facades. In this building the old duct air conditioning system with the low efficiency was replaced by a highly efficient VRV air conditioning system. In the building of Kozani the cooling demand is only 19%, because the shading effect is lesser because the glazing is light absorbing. The thermal comfort area could be increased by 2 and 2,5 0C (in the Thessaloniki and the Kozani building respectively) due to the velocity increase and air humidity drop.

6.3 Natural lighting

The replacement of old technology incandescence and fluorescence lamps, with new technology lamps, lead to a 19% consumption decrease, and to an increased luminance level of 500 lux/m2. If the luminance level was not improved the consumption could be decreased by 48%. The natural lighting level and the glare problems were also improved near the IT equipment areas, implementing venetian blinds.

6.4. Internal gains and IT equipment

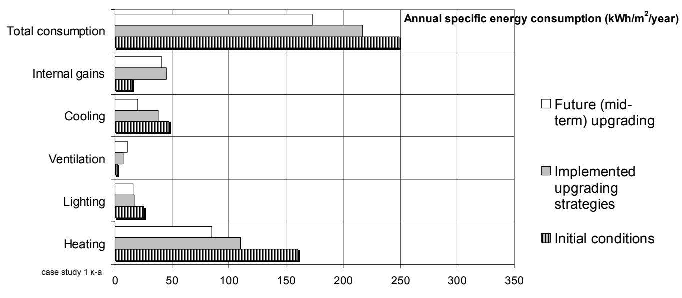
In both examined cases, it was not possible to decrease energy consumption due to IT equipment, because an IT renovation and implementation project was on the run. A large number of personal and mainframe computers, CRT and TFT displays, racks, and other similar equipment was installed and the electricity consumption was increased up to 2,5 times. Therefore, the heating demands are decreased and the cooling demands were increased, battling the cooling measures described in the previous paragraph.

6.5 Potentials for future (mid-term) upgrading

The potentials of future mid-term upgrading is examined alternatively for the third-phase, following the initial phase and the phase of the implementation of the upgrading strategies. In this future (mid-term) upgrading, the main parameters are: highly efficient automated elevators, replacement of old boilers, extensive external shading, equipment for recuperation of heat at the mechanical ventilation system and additional insulation of the building shell. The proposed measures per phase and building are presented in Table 2.

Table 2. Actions of upgrading and phases of implementation

Upgrading phase	*Proposed energy efficiency measures*	*Building in Thessaloniki*	*Building in Kozani*
Implemented upgrading strategies	Roof insulation	Improvement	No
	Double glazing	No	No
	Heating system	Replacement	Improvement
	Cooling system	Replacement of old A/C units with new efficient VRV units	Installation of central fan coil cooling system
	Mechanical/hybrid ventilation	Installation (90%)	Installation (10%)
	Internal shading	Installation	Installation
	Energy efficient lamps	Yes	Yes
	Improvement of natural lighting	Yes	Yes
	Energy efficient office IT equipment	Yes	Yes
future (mid-term) upgrading	Wall insulation	Yes	Yes
	Roof insulation	Re-construction	Improvement
	External shading	Yes	No
	Heat recuperation at the ventilation system	Yes	Yes
	Elevator automations and upgrading	Complete replacement	No
	Hot water for users	Yes	Yes
	Mechanical/hybrid ventilation	Installation (the rest 10%)	Installation (the rest 90%)



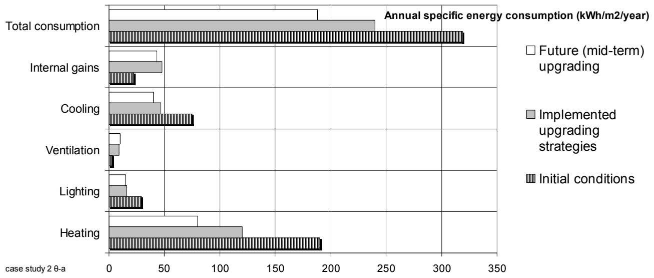


Fig. 6. Specific energy consumption for the examined office buildings, for energy balance parameters, per phase: building in Thessaloniki (upper) and Kozani *(lower)*

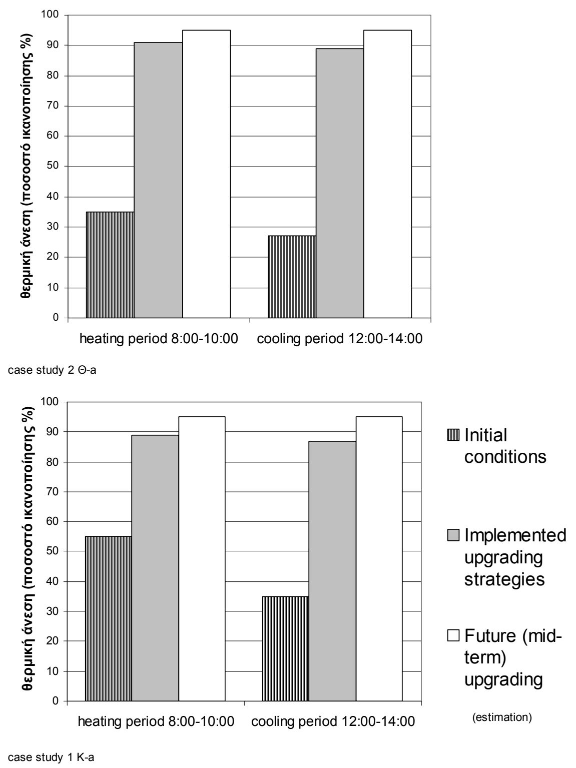


Fig. 7. Thermal comfort in the examined buildings: building in Thessaloniki (upper) and Kozani (lower)

VII. CONCLUSIONS AND OUTCOMES

Two representative case studies of office buildings were examined in the area of Northern Greece in the cities of Thessaloniki and Kozani, within the frames of an upgrading project of office buildings of the public sector in order to improve their energy efficiency. Energy audits and energy simulations were performed for three design phases: a) the initial conditions, b) the implemented upgrading strategies and c) for the future (mid-term) upgrading. Some of the proposed measures were implemented during the existing upgrading program and the others were programmed for the mid-term upgrading, according to the roll out project. Significant energy savings were achieved in both cases. The most effective measures were the installation of double-glazing, the improvement of the insulation of the roof and the external walls, the solar shading and the natural ventilation strategies, the installation of highly efficient HVAC systems and the efficient lighting. The energy savings overcome the problems of the increased ventilation that proved to be necessary in the lounge areas and the very increased internal gains due to the new increased IT equipment.

In the office building in Thessaloniki which was constructed before the Greek insulation regulation and it is practically non insulated, the heating demand was decreased at 63% and could be further deceased at 42% if the mid-term measures are going to be implemented. The respective figures for the office building in the city of Kozani were 69% and 52% of the initial values. The cooling demands were decreased due to proper shading and natural ventilation at 63% and at 53% for the two respective phases of the Thessaloniki building. The respective values of the Kozani building were 81% και στο 43%, because the natural cooling was not implemented at the initial phase.

The improvement of the thermal comfort sense of the inhabitants as traced by the questionnaires proved to be significant. Among others as derived from fig. 7, the percentage of satisfied was moved from 35% in the initial conditions phase to 91% in the implemented upgrading phase at the Thessaloniki building, during the heating period. The values for the cooling period at the same building were moved from 27% to 89% for the respected phases. These values for the Kozani building were moved from to 55% to 89% for the heating period and from 35% to 87% for the cooling period respectively. The IEQ in the working places could also be significantly improved, even from the second phase of the upgrading.

Estimating all the described upgrading action as a total, it could be derived that there are significant potentials for energy renovation and management in office buildings in Northern Greece. Adequate and flexible energy management and upgrading strategies can be adjusted to the existing building project plans.

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