Feasibility assessment and investment-proposal optimization for an NZEB

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Abstract With the Near Zero-Energy Building concept being strongly supported by European Union [1] yet not meeting enough market uptake already the work here is focused on identifying which key parameters would make such a concept investment-attractive. Three locations on different climatic regions are chosen with 3 different levels of insulation and their thermal performance is simulated through the EnergyPlus software. For each set of findings a highly efficient system of on-site PV generation, heat pump, hot water production and thermal storage is cost-optimally sized and the final cost, emissions and indoor comfort results are compared among them and contrasted to a nowadays conventional heat and hot water system. The optimal thermal-equipment arrangement is chosen and the cost & emissions impact of it is assessed for new buildings and renovations alike. The final results indicate the profitability of a more efficient building system and its significant impact in curbing CO_2 emissions from the building sector.

Introduction

Building sector in Europe is responsible for 40% of final energy consumption and 36% of total European GHG emissions [2]. With households consuming 24.8% of final energy and energy poverty being still a major issue in Europe [3], a focus on reducing energy consumption in households seems to have multiple financial, environmental and social benefits at once and thus inspired the current work.

The energy consumption/performance of a building depends upon various parameters: the climatic region, specific location and surroundings, orientation, architectural design, size, habits of the occupants, efficiency of the chosen equipment and primary sources of energy are only a few of the affecting parameters [4]. For that reason some will have to be arbitrarily set as fixed, upon reasonable assumptions and the rest—ones deemed most crucial—will be the ones to optimize on.

The fixed parameters

The architectural design is the first parameter to be identified. In a rationale of minimising the rent price per tenant (in order to maximise market competitiveness in this aspect) the building use with highest occupant density is chosen: a student residence. Thus a main zone with private rooms is established along with an attached common-use kitchen and the staircase to reach the upper floors. This design is important also because it allows to focus the thermal conditioning to one zone of the building (excluding the kitchen and staircase) and thus minimise further the energy costs. Eventually the design concludes to a total floor area of 695.67 m^2 (3 floors) with 29 individual rooms of ~15m^2 each.

The residence occupancy and energy use habits of the occupants (use of electronic equipment) is then assumed based on average student time-schedules and the average national electricity consumption curve.

The power rating of lights and electronics (as well washing machines and electric kitchen stoves) are also determined based on average values.

Domestic Hot Water production which is a large part of a household's energy consumption is also modelled upon average values [5] and corrected for monthly variations [6] in order to yield even more reliable results.

Also the ventilation rate is established. Ventilation is important as it ensures that fresh air enters the building and indoor air quality is maintained pleasant. Yet the fresh air needs thermal conditioning first and thus it affects greatly the energy consumption. Here the ventilation is scheduled according to occupancy as to follow the suggested ASHRAE 62.2 guidelines about minimum air refresh rate per occupant [7].

Lastly the thermostat is set, according to general guidelines the minimum temperature is set at 20 ^{0}C while the maximum at 24 ^{0}C, year round.

The variable parameters and derived cases

Therefore the main sets of parameters left to variate in order to identify the cost-optimal point of the NZEB are the insulation level and the location of the building.

For the insulation level of the building 3 different sets of roof-walls-floor thermal conductivity values were chosen based on the cost-optimal levels proposed for each location from EURIMA on a previous report [8]. The final insulation values are eventually chosen based on the value-for-money of market-available building materials and presented as below in Table 1:

Design	R1	R2	R3
Roof	2.40	2.98	3.89
Walls	2.27	2.91	3.68
Floor	0.79	0.79	1.70

Table 1: R-values (m^2K/W) for each building element of each insulation level

For the locations, in order to diversify the results, 3 locations were chosen for each one of the 3 Hardiness Zones (European wide zones categorised by minimum winter temperatures) that exist within Greece: for Zone 10, Chania; for Zone 9, Athens and for Zone 8, Thessaloniki. Eventually a small substitution had to be made as for the simulation software (EnergyPlus) weather files existed only for Athens and Thessaloniki and not Chania. Thus, as a dummy-location the city of Larnaca in Cyprus was chosen to substitute the weather of Chania, as they are both coastal cities of the same latitude, thus small weather/insolation differences are expected between them.

Design of the building energy-system

As the combinations of locations and insulation levels are established and the heating/cooling/hot-water needs are derived from the simulations, the actual energy consumption must be identified in order to calculate the costs. In an effort to minimise the costs a highly efficient integrated system is devised.

At the core of the system lies the fact that thermal storage is the cheapest form of energy storage available [9]. This in combination with the fact that about 80% of a household's needs are thermal [10] brings rise to the argument that once the heating needs of a household are combined with thermal storage then 80% of its consumption becomes time flexible.

Thus the final energy system arrangement is as following: an on-site PV-array generates electricity for the residence's electric equipment and the heat pump. The heat pump operates as much as possible in times of surplus PV production (from the electronics consumption). In the winter the produced heat is used for heating of the spaces and Hot Water production while in the summer it simultaneously heats up the Hot Water while provides cooling for the indoor spaces. The heat/cold produced at times of PV electricity surplus is stored in insulated water tanks for use throughout the day as thermal comfort needs occur accordingly. To further reduce the heating/cooling needs a mechanical ventilation heat recovery (MVHR) system is installed to recover 84% [11] of the exhausted air's energy.

Methodology

A particular methodology is undertaken in order to optimise the size and running costs of the system. The final heating/cooling needs (after the MVHR) are combined with the hot water needs. The total annual electricity required—for both the heat pump and the electronic equipment—is calculated and the annual grid-bought electricity derived. Then a PV system is added and the daily load of the heat pump is shifted in order to fit the PV generation as much as possible. The addition of the PV system means a capital investment at the present but reduced grid-electricity costs every year on. The size of the PV system is then varied until the Net Present Value of the system with the PV is equal to the NPV of grid-electricity costs without the PV system, over an assumed 30-year expected-payback period of the investment. This way what is achieved is that while maintaining the same financial status of the investment (NPV value), the electricity source is substituted to a large extent by a zero-carbon source (the on-site PV system).

Then for sizing the heat pump the peak load days and the break-even days (where the PV-produced electricity is barely enough to cover the heat pump consumption) are taken into consideration and the minimum peak-power of the heat pump to fulfil the needs is derived.

For the Thermal and Hot Water storage tanks, they are sized according to the maximum daily needs that occur throughout the year.

Results

Prime-criterion, based on cost-optimality, is the minimised final energy consumption. The "energy intensity" of each design for the locations is presented in the Tables 2–4 below:

Design	HP load	Grid-electricity
R1	6,381.13	29,829.18
R2	6,336.43	29,826.12
R3	6,339.90	29,821.10

Table 2: Energy consumption [kWh_e/a] results for Larnaca

Design	HP load	Grid-electricity
R1	6,695.83	31,540.46
R2	6,631.43	31,511.74
R3	6,588.72	31,468.33

Table 3: Energy consumption results for Athens

Design	HP load	Grid-electricity
R1	7,399.66	32,350.40
R2	7,317.63	32,305.12
R3	7,234.94	32,246.59

Table 4: Energy consumption results for Thessaloniki

The first observations are striking as the increase of insulation (a significant invest-ment) seems to achieve—at maximum—an annual reduction of 59 kWh_e, an amount far from being able to financially justify investing in further insulation. Comparing this to the extensive impact that is attributed to insulation on energy savings on literature, an alternative direction is decided in order to assess if the nature of the energy system that is selected can have an even higher impact on energy savings.

Re-orientation

As insulation has proved to have small impact on energy savings here, the bare-minimum amount of insulation—according to existing local regulations [12]—is chosen for each location. To discern now more clearly the impact of an efficient (and naturally expensive) energy system, a simpler system (based on common Greek-market practices) is synthesised and the results are compared among them.

The common system is composed of a central oil-furnace (running on Diesel fuel) with a heat distribution system through pipes and radiators. The hot water is provided to a minimum extent—as defined in each location from the regulations—by solar-thermal collectors and the rest by an electric resistance. This design has some inherent disadvantage compared to the integrated-HVAC system previously used as A) is has no ventilation and heat recovery system (which is expected to have detrimental effects on Indoor Air Quality and energy consumptions and B) has no capacity for cooling (yet this is the common practice in Greece) which means that inevitably the thermal comfort in summer will not be achieved as outdoor temperatures can easily reach up to 40 ^{0}C.

New results

Therefore the simulations are once more run and the results derived are converted to costs (through average electricity and diesel prices) and compared as in the Table 5 below:

	Larn.	Ath.	Thess.
HVAC elec. (kWh_e/a)	29,832.76	31,530.42	32,313.00
HVAC cost (€/a)	**1,789.97**	**1,891.83**	**1,938.83**
Common elec. (kWh_e/a)	39,938.04	41,444.33	42,713.00
Common Fuel (L/a)	94.01	517.29	1,565.55
Common cost (€/a)	**2,491.42**	**3,010.16**	**4,147.12**

Table 5: Annual energy consumption and corresponding costs per location per design

The results clearly indicate, as expected, that the HVAC system has a much lower energy consumption (less electricity and no fuel at all) compared to the common energy system. This comes at significantly lower costs and naturally less emissions. Additionally to that the common system will inevitably come along with high thermal dis-comfort in the summer months where it is unable to provide cooling.

From the facts above the long-term superiority of a highly efficient HVAC system as the one proposed here is proven. The only concern is the higher investment cost that will have to be taken into consideration for the final verdict.

HVAC-design costs & emissions

Overall the final cost of a new building with the finally-decided (minimum) insulation and the corresponding HVAC energy system is determined. The occurring emissions are also calculated and presented together in the Table 6 below:

	Larn.	Ath.	Thess.
CAPEX new-build. (€/m²)	1,249.60	1,254.52	1,259.45
CAPEX Renovation (€/m²)	105.38	110.45	115.54
OPEX (€/m²/a)	2.57	2.72	2.79
CO_2 emiss. (kg/m²/a)	21.95	23.20	23.78

Table 6: normalised per floor area cost and emission values for the HVAC system buildings

The cost of renovation is also calculated here as in order to reach the emissions goals of the building sector only new low-emission buildings will not suffice.

Having the CAPEX of a new NZEB residence building is not directly indicative of its market rent-price. Now, by assuming that the building is created as 30 year expected-payback investment upon a 5.01% business loan [13] the occurring monthly installments (i.e. the required rents) come at the following amount per location, as in Table 7 below:

	Larn.	Ath.	Thess.
Rent (€/m²/m)	6.72	6.74	6.77

Table 7: Normalised per floor area market-rent at locations of interest

Current-Market costs & emissions

The uptake of any new or “retrofit” NZEB implementation depends mostly upon its market competitiveness, thus it is crucial which is the current condition of the real estate market in the assessed locations. Also the potential of reduction in CO_2 emissions depends on the current levels of building emissions. Upon a market research for the rent prices [14] in apartments/rooms and the current emissions of apartment-block buildings [15] the following values are derived and presented in Table 8 below:

	Larn.	Ath.	Thess.
Rent (€/m²/m)	7.30	5.67	6.56
Energy (€/m²/a)	17.50	19.55	25.58
CO2 emiss. (kg/m²/a)	64.31	71.84	94.02

Table 8: normalised per floor area monthly rent and annual emission values for the current market-buildings

Comparison of new-NZEB vs Market housing

Having both the values of the new-NZEB and Market rents and energy costs a final comparison can be executed. For more representative results the comparison is performed on a 24m² room size basis, the equivalent of the proposed NZEB-residence’s total area divided by the total number of occupants, and the results are presented at the Table 9 below:

(€/m)	Larn.	Ath.	Thess.
NZEB rent	161.10	161.73	162.37
NZEB energy	5.15	5.44	5.57
NZEB sum	**166.25**	**167.17**	**167.94**
Market rent	175.20	136.00	157.50
Market energy	35.00	39.10	51.16
Market sum	**210.20**	**175.10**	**208.66**
(NZEB) – (Market)	**-43.95**	**-7.92**	**-40.72**

Table 9: Comparison of monthly costs for NZEB and Market rooms

As observed the construction of a new room/apartment NZEB building is not usually competitive, as in 2 of the 3 locations the occurring rent price is higher than the market’s (natural given the economic recession in Greece, reflected normally in the real estate sector). Yet what makes the difference is the extremely lower energy expenses that manage—when co-assessed with the rent—to achieve competitive monthly sums.

Therefore here it occurs that the NZEB concept is market-competitive strictly due to its extremely low energy consumption.

Profitability of Renovations

While new NZEBs might be competitive and their uptake is (rationally) expected, no actual reduction in GHG emissions will be achieved if no energy-renovations are undertaken extensively as well. For that reason the profitability of such renovations is critical to be assessed as well.

Thus, the cost of installing additional insulation (up to the minimum of local regulations) and the HVAC system is normalised per floor area and the energy (cost) savings are derived. The payback period is finally calculated (for own funds and for a bnk-loan case) and so the overall attractiveness of the renovation-investment is concluded, as in Table 10 below:

	Larn.	Ath.	Thess.
CAPEX (€/m^2)	105.38	1101.45	115.54
Savings (€/m^2/a)	14.92	16.83	22.79
Payback (a)	**7.06**	**6.56**	**5.07**
5.01% loan payoff (<a)	**9**	**9**	**6**

Table 10: Assessment of financial attractiveness of NZEB-Renovations

The results are up to expectations. According to general literature, the payback period of energy saving investments is 5 – 10 years and results here are in alignment.

An investment with a pay-back of less than 10 years can be considered a rather good investment if the risk is low. The problem in the case of energy-renovations is that home-owners are not aware of the reliability and the benefits of such renovations and thus perceive them as too risky to undertake for such long pay-back periods.

What occurs from this final remark is that once more, dissemination of information is crucial for the successful proliferation of NZEB concepts.

NZEB scale-up and emissions reduction

As the financial attractiveness and better comfort achieved through the proposed NZEB energy-system is illustrated already, what is left is to assess the extent at which the implementation of the concept can achieve a significant Climate-Change-mitigation impact.

Initially, to put that in perspective, the GHG emissions 2020 goal is to achieve 20% less emissions than the 1990 levels. Now assuming a proportional distribution of emissions-reduction among regions and sectors this concludes to the fact that the Greek apartment-block residential buildings sector must achieve a net reduction of 680.4 ktCO_2eq [16], [15]. To assess the achieve-ability of this the additional emissions of new buildings will have to be co-estimated with the achieved emission reduction from renovated buildings.

For the new buildings, the NZEB emissions are reminded here and for comparison the ones that would occur from a business-as-usual (i.e. current market) energy-system are presented, as below in Table 11:

	Larn.	Ath.	Thess.
NZEB CO_2 (kg/m^2/a)	21.95	23.20	23.78
Market CO_2 (kg/m^2/a)	64.31	71.48	94.02
(NZEB) – (Market) (kg/m^2/a)	-42.36	-48.28	-70.24

Table 11: Building emissions intensity difference per location

Based on statistical records of Greece the average annual rate of new building permits is around 2,659,000 m^2/a [17]. When these are distributed proporionally to the climate zones of Greece the eventual outcome—for a 100% NZEB new apartment buildings—is an increase of CO_2 emissions at a rate of 19.85 kt/a.

This is the best-case scenario of increase of emissions in the apartment-building sector. This impact will have to be more than counter-effected by the renovations if a reduction in emission levels is truly sought here. Initially the effectiveness of renovations in reduction of emissions has to be assessed. Using the data of Table 11 previously, the difference values are not only the extra emissions avoided for the new buildings but also the reduction of emissions in the renovated buildings. Therefore the required value for the estimations is the renovation rate.

From the same sources it occurs that renovations of buildings are currently undertaken in Greece under a standard rate of ~25,000 households per year. For the average residence house of 75 m^2 this means a total floor area of 1,870,000 m^2/a [15]. For a distribution of renovations among climatic zones in Greece similar to that of new building permits the end result is an achieved reduction of CO_2 emissions at 101.16 kt/a.

Combining together the additional emissions and reduction in emissions from the current building and renovation rates a final value of net reduction of 81.31 kt/a occurs. This, compared with the estimated goal of total sector reduction of 680.4 ktCO_2eq yields eventually a goal-reach finish line within 2025.

Even if the goal of “20% less emissions by 2020” for the sector is achieved 5 years overdue, this is a highly encouraging result because—realistically speaking, given the current market conditions and financial situation in Greece—it is actually fortunate to have anyway a prospect of achieving such a goal anytime in the near future.

Conclusions

In the current work the profitability and market competitiveness of a specific NZEB have been assessed in an effort to identify the critical parameters.

While the original remark—when it comes to energy-savings in buildings—is increasing the insulation, the current thermal-simulation results have indicated that this makes little difference.

The focus then has shifted to the efficiency of the proposed energy-system: a heat_pump-based, A/C and Hot water, PV-powered, with thermal storage system. As this was compared to a today's conventional energy system and the current market condition it occurred that indeed, this integrated-HVAC system out-performed by far in terms of lower energy consumption, lower emissions and higher offered indoor thermal comfort both of the other assessed systems.

Essentially, this indicates that—since the proposed arrangement does not exist readily in the market—potentially more focus should be paid at increasing the efficiency energy systems rather than investing in additional insulation.

Finally, from a Climate Change perspective, the overall impact of implementing the herein proposed NZEB system is assessed, for the current average building-raising and –renovating rates in Greece. In such a case then the proportional-to-apartment-building-sector CO_2 emissions reduction goal for 2020 will be eventually achieved in 2025.

The final remark of the work performed here is that even though investing in NZEB concepts such as this one proves to be financially, environmentally and in terms of indoor comfort beneficial, very little uptake currently exists, an irrational outcome. Therefore other issues are expected to act as impediments, ones mostly relating to emotional and psychological reasons such as lack of sufficient information to the home-owners and distrust from their behalf on the new technologies. When this is combined with the long payback period of such investments, the perceived risk seems too high and thus no investments and any changes whatsoever are performed.

Therefore the final suggestion here is a call for specialised groups who understand and can properly evaluate and execute such interventions to standardise and implement these concepts as for the market to begin realising their inherent value and familiarise progressively with them. As the concept begins to spread, the uptake rate will naturally increase and only then the NZEB concept will become a real new market option, allowing eventually for an actual chance to mitigate the GHG impact from the building sector.

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