# Ground Source Heat Pump systems for nearly zero energy buildings: Energy, environmental and economic assessment for Cyprus

**Project No: DIDAKTOR/0311/37**


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Nicosia, May 25, 2015

# Project Overview

The aim of the project is to assess the use of GSHP (autonomous, hybrid and conjugated) in nearly zero energy buildings of Cyprus. This assessment is primarily focused on:

- Energy (primary energy reduction)
- Environmental ($CO_2$ emissions)
- Economic (NPV index in lifetime)

# Selection of the typical reference buildings for Cypriot building stock

Within this frame the following actions have taken place:

- Detailed analysis on the Statistical Reviews
  - Building permits 2003-2012
  - Building typology
  - Building area and units

| Κώδικας CC 1996 | ΚΑΤΗΓΟΡΙΑ ΕΡΓΟΥ | 2012 | | | 2011 | | | 2010 | | | 2009 | | | 2008 | | | 2007 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Αριθμός | Εμβαδόν (μ²) | Αριθμός οικιστ. | Αριθμός | Εμβαδόν (μ²) | Αριθμός οικιστ. | Αριθμός | Εμβαδόν (μ²) | Αριθμός οικιστ. | Αριθμός | Εμβαδόν (μ²) | Αριθμός οικιστ. | Αριθμός | Εμβαδόν (μ²) | Αριθμός οικιστ. | Αριθμός | Εμβαδόν (μ²) |
| **11** | **Οικιστικά κτίρια** | **4,439** | **1,171,411** | **5,879** | **5,296** | **1,635,372** | **8,839** | **6,426** | **2,448,379** | **14,312** | **6,482** | **2,723,777** | **16,688** | **6,879** | **3,187,401** | **20,082** | **7,536** | **3,218,239** |
| 111 | Μονοκατοικίες | 3,593 | 727,663 | 2,761 | 4,220 | 942,996 | 3,731 | 5,036 | 1,252,538 | 5,511 | 4,988 | 1,298,410 | 6,233 | 5,110 | 1,357,098 | 6,263 | 5,725 | 1,474,442 |
| 112 | Κτίρια με δύο ή περισσότερες κατοικίες | 841 | 442,314 | 3,118 | 1,070 | 688,555 | 5,108 | 1,386 | 1,189,575 | 8,801 | 1,491 | 1,419,835 | 10,455 | 1,765 | 1,829,731 | 13,819 | 1,808 | 1,740,074 |
| | Διπλοκατοικίες | 315 | 114,526 | 820 | 357 | 184,089 | 1,520 | 323 | 149,247 | 1,039 | 296 | 144,248 | 1,012 | 414 | 267,178 | 1,877 | 597 | 358,095 |
| | Οικιστικές πολυκατοικίες | 407 | 238,255 | 1,986 | 579 | 376,622 | 2,906 | 899 | 757,649 | 5,954 | 1,058 | 1,005,834 | 7,827 | 1,206 | 1,300,902 | 10,399 | 1,057 | 1,125,851 |
| | Μικτές πολυκατοικίες | 116 | 89,533 | 309 | 126 | 116,099 | 571 | 149 | 200,367 | 829 | 123 | 240,213 | 1,266 | 119 | 197,044 | 761 | 127 | 185,188 |
| | Συγκροτήματα εξοχ. διαμερισμάτων | 3 | 0 | 3 | 8 | 11,745 | 111 | 15 | 82,312 | 979 | 14 | 29,540 | 350 | 26 | 64,607 | 782 | 27 | 70,940 |
| 113 | Συλλογικές κατοικίες | 5 | 1,434 | | 6 | 3,821 | | 4 | 6,266 | | 3 | 5,532 | | 4 | 572 | | 3 | 3,723 |
| **12** | **Μη οικιστικά κτίρια** | **1,222** | **325,057** | | **1,199** | **612,726** | | **1,221** | **447,599** | | **1,532** | **403,787** | | **1,088** | **494,381** | | **1,102** | **385,980** |
| 121 | Ξενοδοχεία και παρόμοια κτίρια | 122 | 25,612 | | 173 | 29,037 | | 152 | 10,410 | | 143 | 7,774 | | 138 | 56,663 | | 162 | 18,192 |
| | Ξενοδοχεία | 7 | 19,116 | | 17 | 18,132 | | 15 | 5,104 | | 7 | 2,296 | | 7 | 1,633 | | 9 | 5,388 |
| | Τουριστικά διαμερίσματα και χωριά | 16 | 3,065 | | 29 | 4,437 | | 23 | 1,947 | | 16 | 1,448 | | 22 | 49,442 | | 27 | 7,487 |
| | Εστιατόρια, καφετέριες και μπυραρίες | 98 | 2,841 | | 125 | 6,188 | | 114 | 3,359 | | 119 | 3,567 | | 108 | 4,607 | | 123 | 3,793 |
| | Άλλα κτίρια διακοπών | 1 | 590 | | 2 | 280 | | 0 | 0 | | 1 | 463 | | 1 | 981 | | 3 | 1,524 |
| 122 | Κτίρια γραφείων | 96 | 89,715 | | 125 | 184,534 | | 137 | 172,140 | | 106 | 103,545 | | 113 | 129,078 | | 90 | 75,699 |
| 123 | Κτίρια χονδρικού και λιανικού εμπορίου | 98 | 21,748 | | 125 | 133,126 | | 109 | 35,560 | | 131 | 58,847 | | 112 | 51,137 | | 114 | 75,709 |
| 124 | Κτίρια μεταφορών και επικοινωνιών | 2 | 5,872 | | 10 | 28,731 | | 3 | 13,657 | | 2 | 2,727 | | 0 | 0 | | 0 | 0 |
| 125 | Βιομηχανικά κτίρια και αποθήκες | 207 | 119,703 | | 219 | 188,681 | | 237 | 148,434 | | 281 | 166,337 | | 254 | 211,877 | | 284 | 163,816 |
| 126 | Κτίρια για δημόσια θεάματα και για ψυχαγωγικούς, εκπαιδευτικούς ή υγειονομικούς σκοπούς | 127 | 32,161 | | 164 | 31,890 | | 134 | 44,526 | | 116 | 26,089 | | 91 | 23,422 | | 92 | 39,307 |
| 127 | Άλλα μη οικιστικά κτίρια | 570 | 30,246 | | 383 | 16,727 | | 449 | 22,872 | | 753 | 38,468 | | 380 | 22,204 | | 360 | 13,257 |
| **2** | **Έργα πολιτικού μηχανικού** | **1,000** | **3,398** | | **335** | **4,939** | | **409** | **21,927** | | **319** | **8,895** | | **283** | **7,327** | | **250** | **8,587** |
| **3** | **Διαίρεση οικοπέδων και δρόμοι** | **453** | | | **590** | | | **641** | | | **543** | | | **585** | | | **633** | |
| **4** | **Κατασκευή δρόμων** | **58** | | | **86** | | | **80** | | | **74** | | | **61** | | | | |
| | **ΣΥΝΟΛΟ** | **7,172** | **1,499,866** | **5,879** | **7,506** | **2,253,037** | **8,839** | **8,777** | **2,917,905** | **14,312** | **8,950** | **3,136,459** | **16,688** | **8,896** | **3,689,109** | **20,082** | **9,521** | **3,612,806** |
| | Μεγάλα έργα | 931 | 698,263 | 2,467 | 618 | 1,232,722 | 4,087 | 946 | 1,628,332 | 8,160 | 1,023 | 1,767,808 | 9,744 | 1,206 | 2,183,574 | 12,515 | 1,150 | 1,973,103 |
| | Μικρά έργα | 6,241 | 801,603 | 3,412 | 6,888 | 1,020,315 | 4,752 | 7,831 | 1,289,573 | 6,152 | 7,927 | 1,368,651 | 6,944 | 7,690 | 1,505,535 | 7,567 | 8,371 | 1,639,703 |

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# Selection of the typical reference buildings for Cypriot building stock

- In-situ visits on recently finished and under construction buildings in order to capture the real construction practice and characteristics
- Discussions with construction engineers and designers

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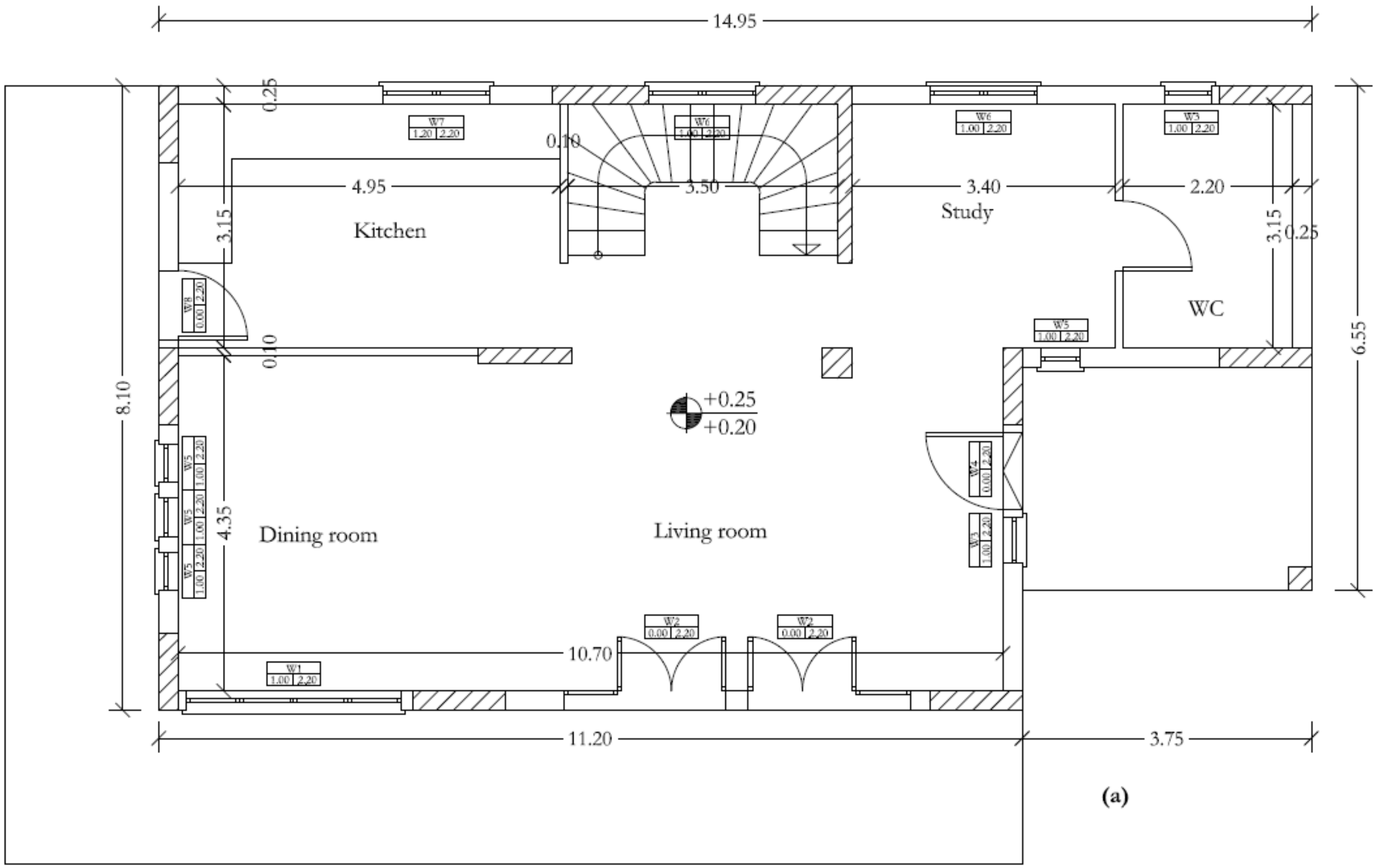
# Architectural plan of the single-family reference building

Single-family house – Ground floor

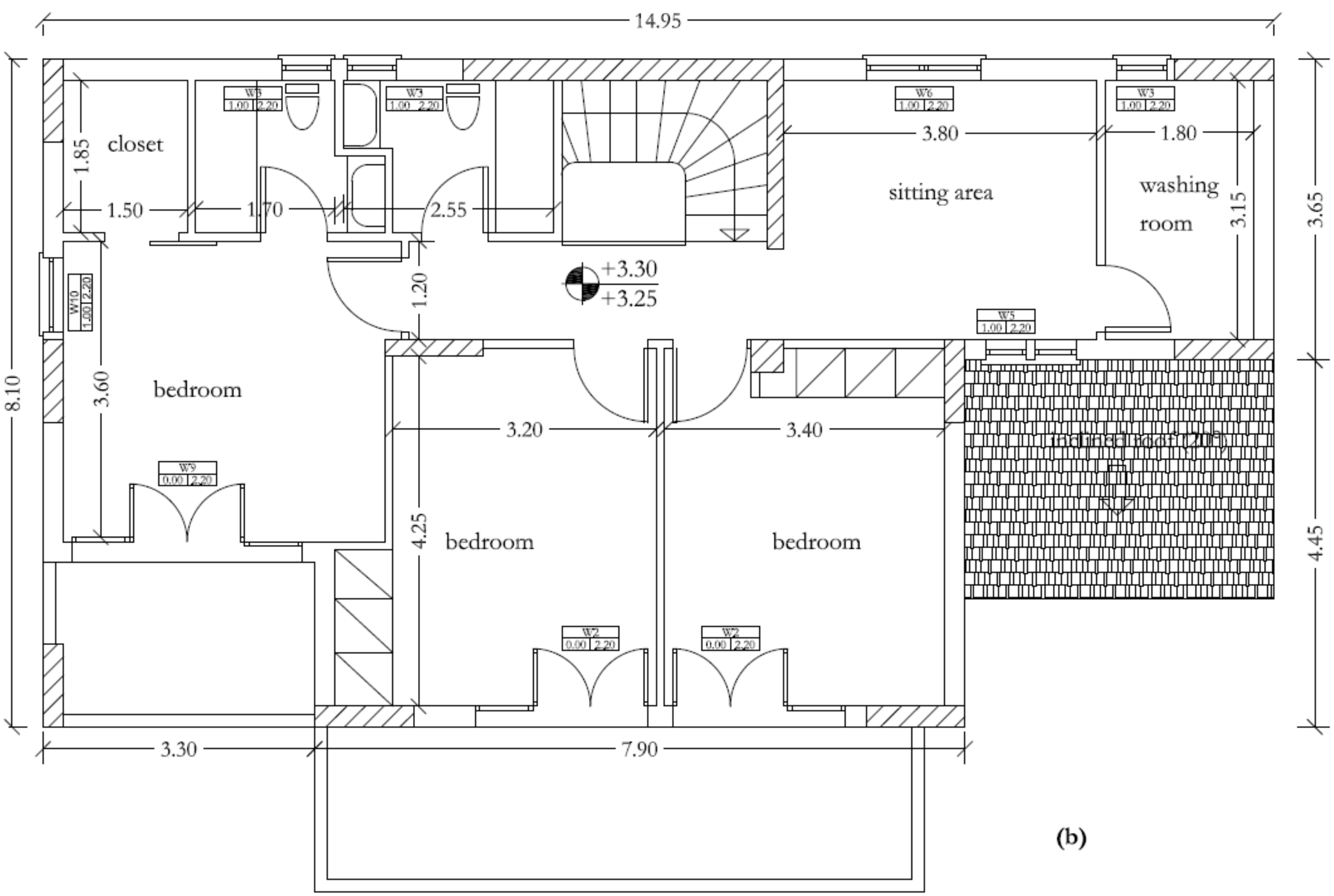



2 levels

202.2 m$^2$

# Architectural plan of the single-family reference building

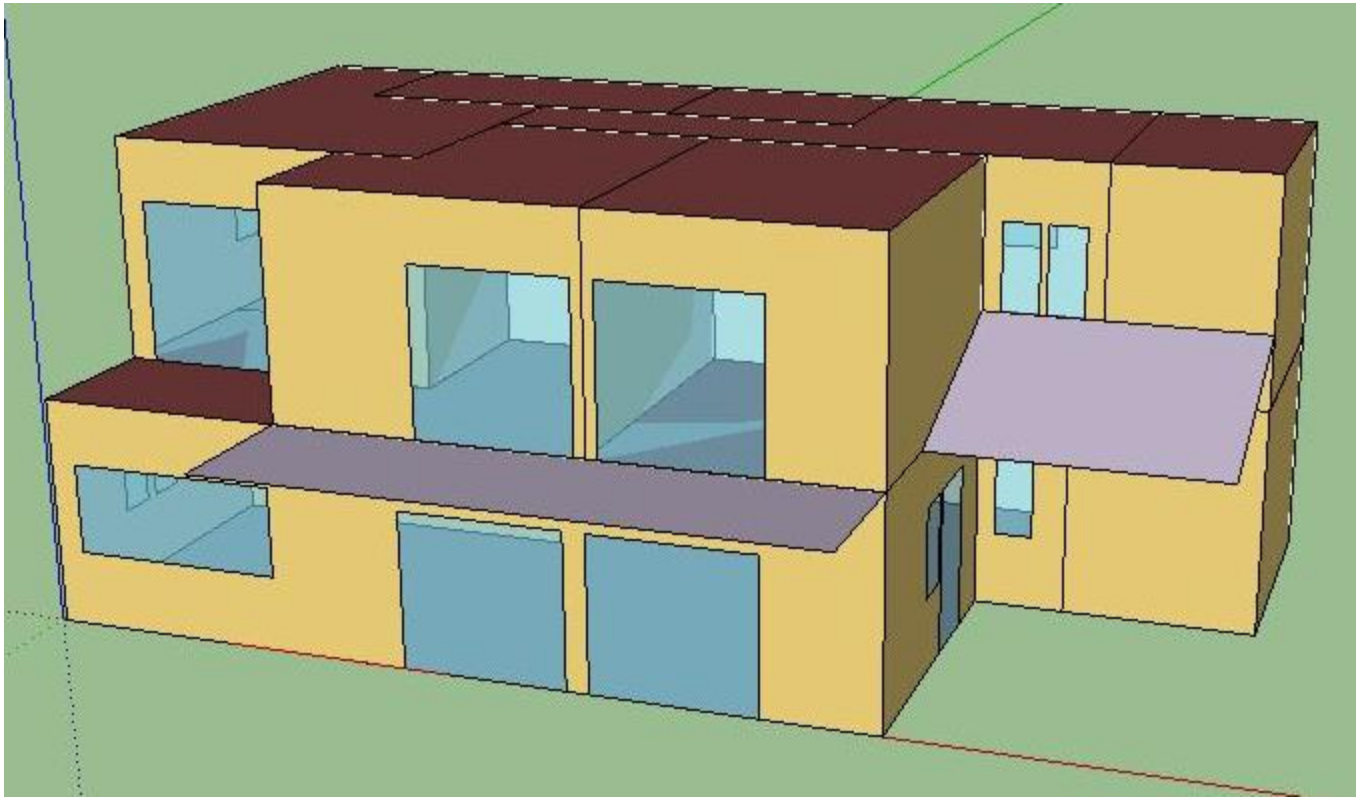
Single-family house – Upper floor




(b)

# Geometrical model of the single-family reference building

Single-family house



# Thermal characteristics of the single-family reference building

Current practice: In compliance with current Regulations of Energy Efficiency

| Building Element | Thermal Transmittance U [W/(m²·K)] | |
|---|---|---|
| | Case Study | ΚΔΠ 432/2013 |
| Masonry | 0,58 | 0,72 |
| Reinforce Concrete | 0,69 | 0,72 |
| Roof | 0,61 | 0,63 |
| Openings | ($U_f$/$U_g$): (2,8/2,8) | $U_w$: 3,23 |

The energy demand of the single-family reference building was calculated on an hourly basis with the aid of EnergyPlus software in 5 representative locations of Cyprus

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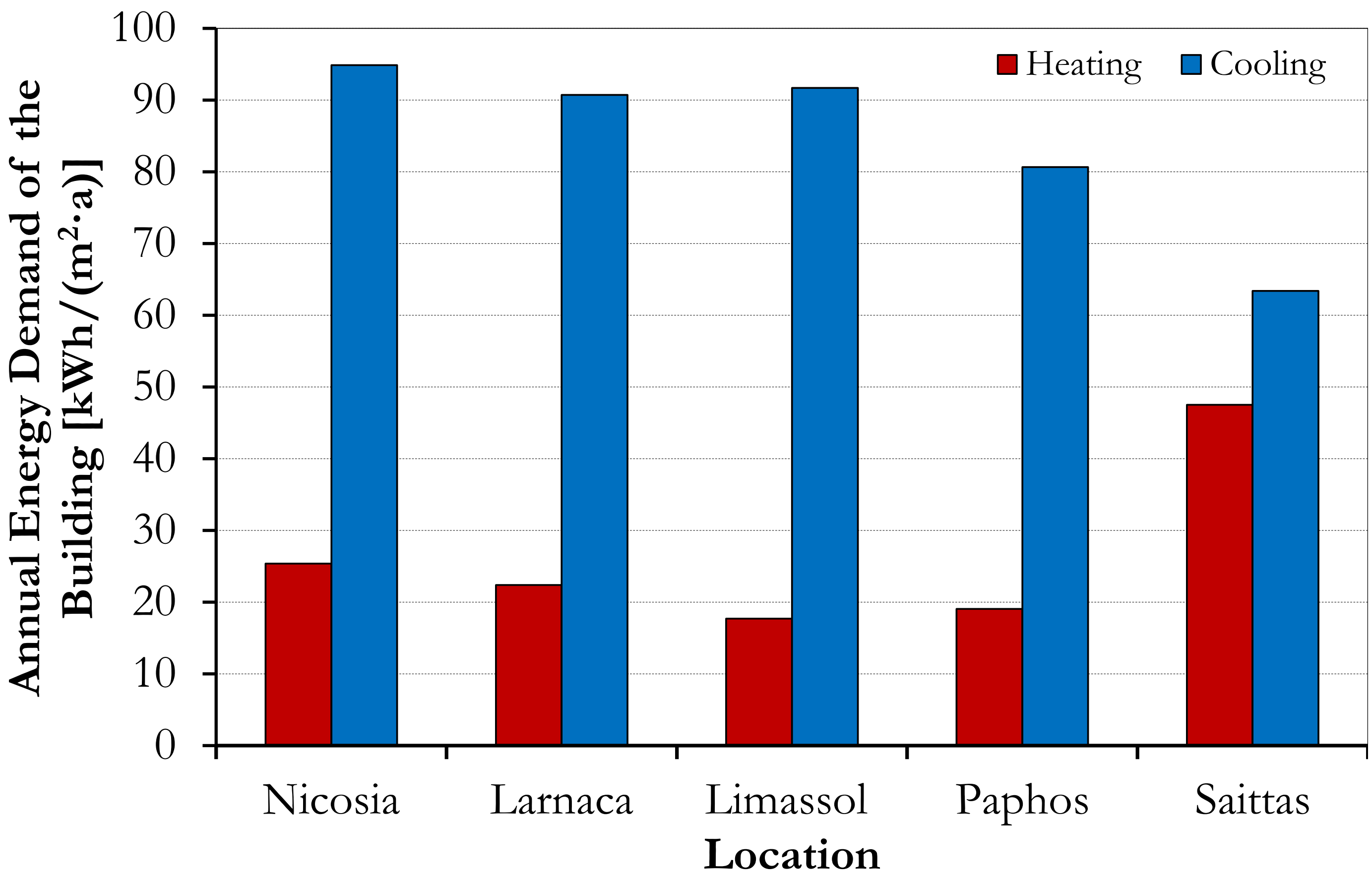
# Energy demand of the single-family reference building

Single-family building, energy simulation results – Current practice

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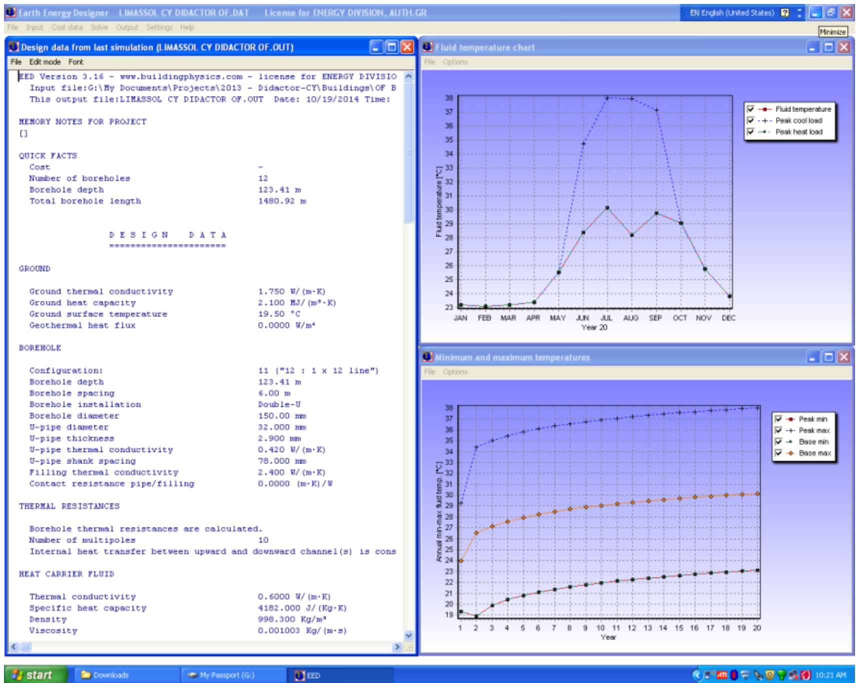
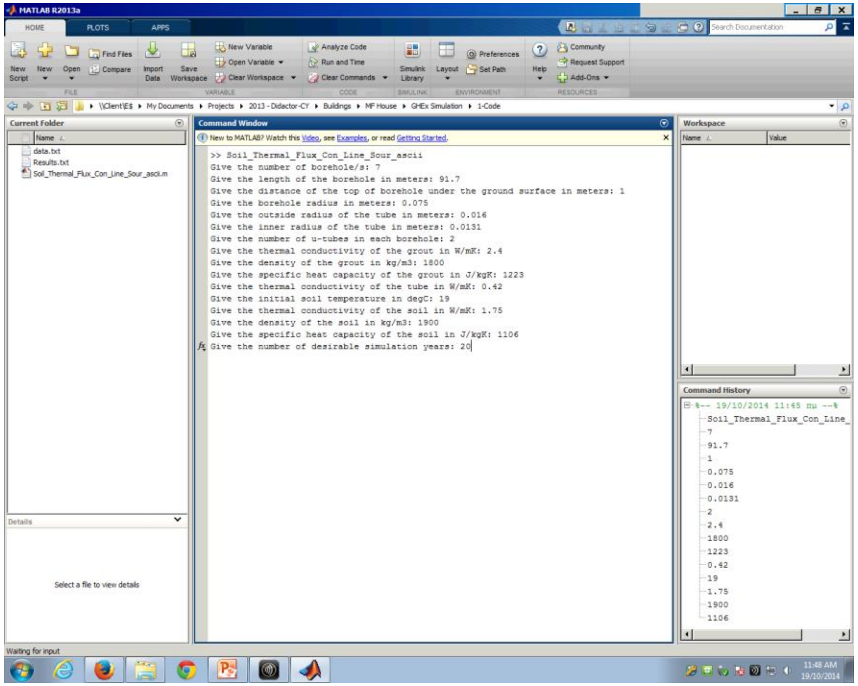
# Design and simulation of the Ground Source Heat Pump system

GSHP Design: EED 3.16

Energy consumption of the GHP: In-house software

Energy consumption of the circulation pump: Methodology proposed by Sfeir et al, 2005




ΞΕΡ

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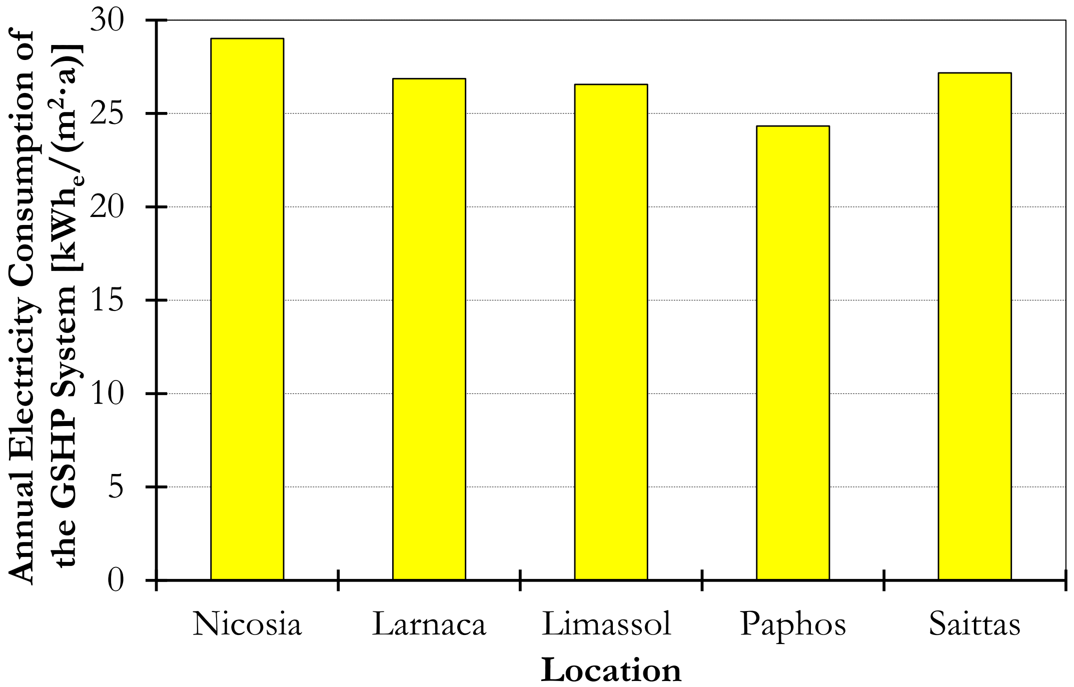
# Design and simulation of the Ground Source Heat Pump system

Single-family building, design and simulation results – Current practice

| Location | Boreholes x Length | Configuration |
|---|---|---|
| Nicosia | 4 x 65 m | L: 2 X 2 |
| Larnaca | 4 x 67 m | L: 2 X 2 |
| Limassol | 4 x 64 m | L: 2 X 2 |
| Paphos | 4 x 52 m | L: 2 X 2 |
| Saittas | 3 x 55 m | Line: 1 x 3 |

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# Energy, Environmental and Economic Analysis – Single-family building

Analysis of the **current building practice**

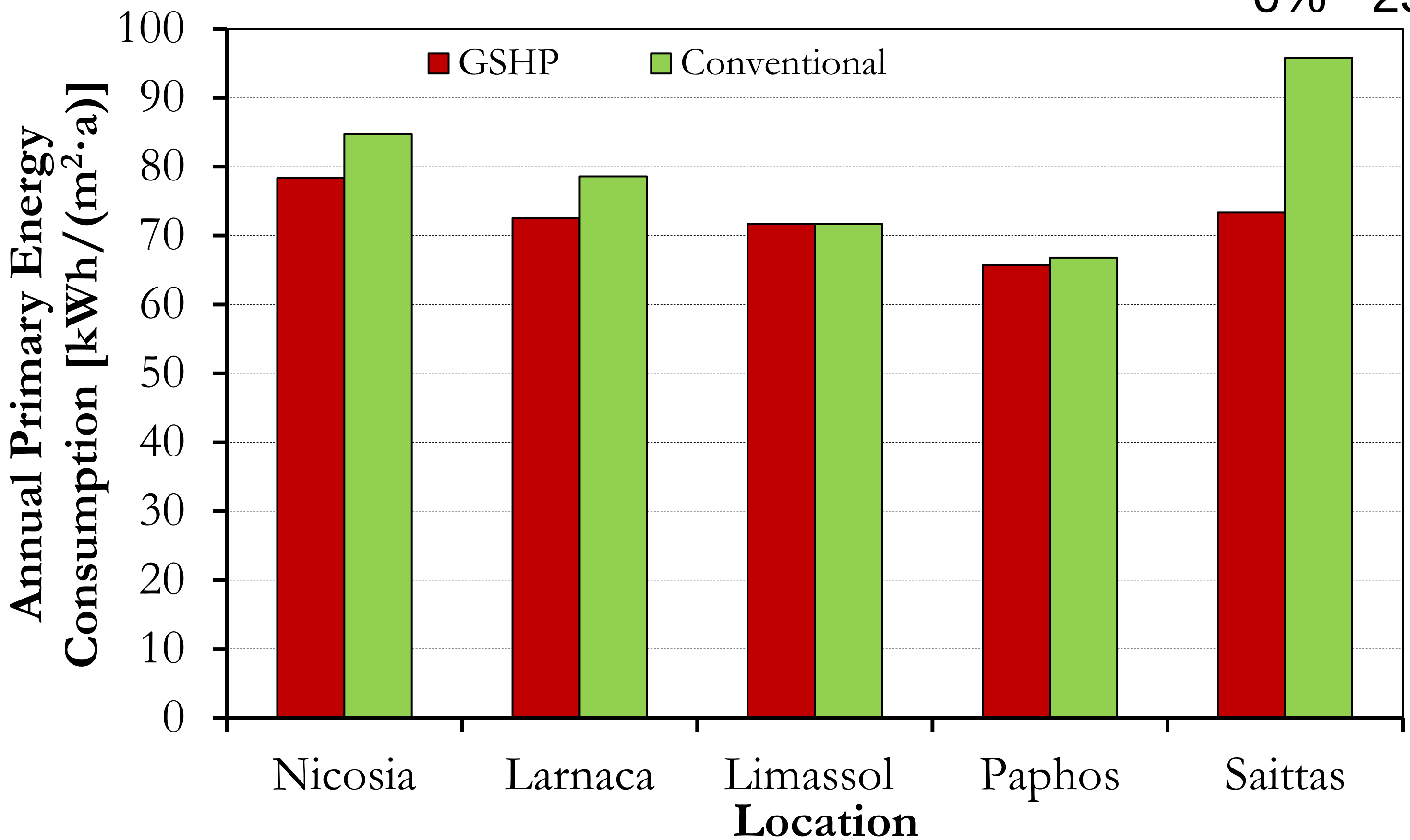
Conventional system:

- Oil-fired boiler and air-to-air-heat pump and
- LPG-fired boiler and air-to-air-heat pump and
  - Boiler efficiency: 0.92
- Heat pump:
  - Air-to-air split type
  - Analysis on an hourly base using the:
    - Energy demand of the building envelope,
    - Ambient temperature retrieved from Meteonorm database
    - EER provided by HP manufacturer

# Energy, Environmental and Economic Analysis – Single-family building

Single-family building – Energy evaluation

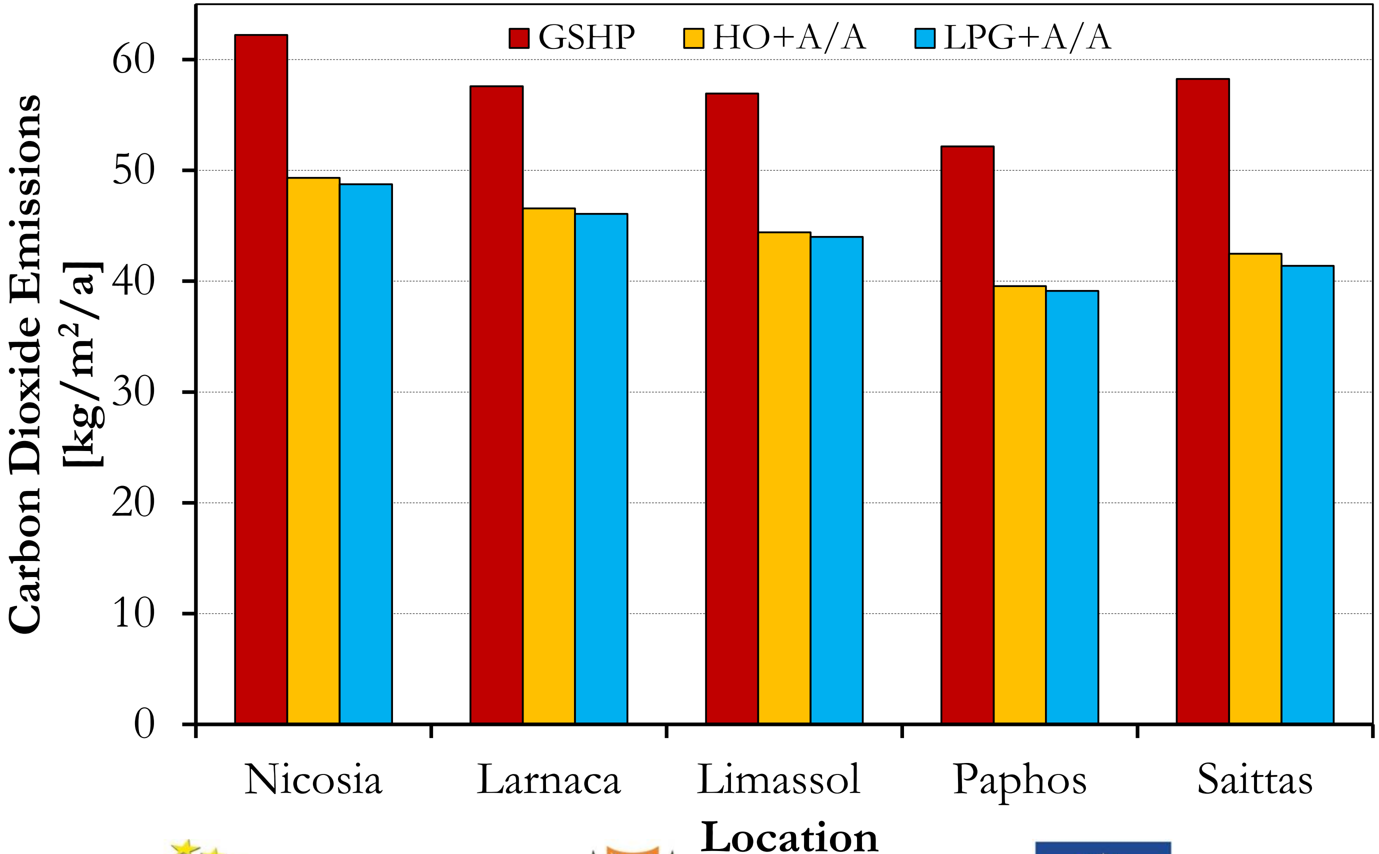
0% - 23.4% less



# Energy, Environmental and Economic Analysis – Single-family building

Single-family building – Environmental evaluation

19.15% - 28.95% higher

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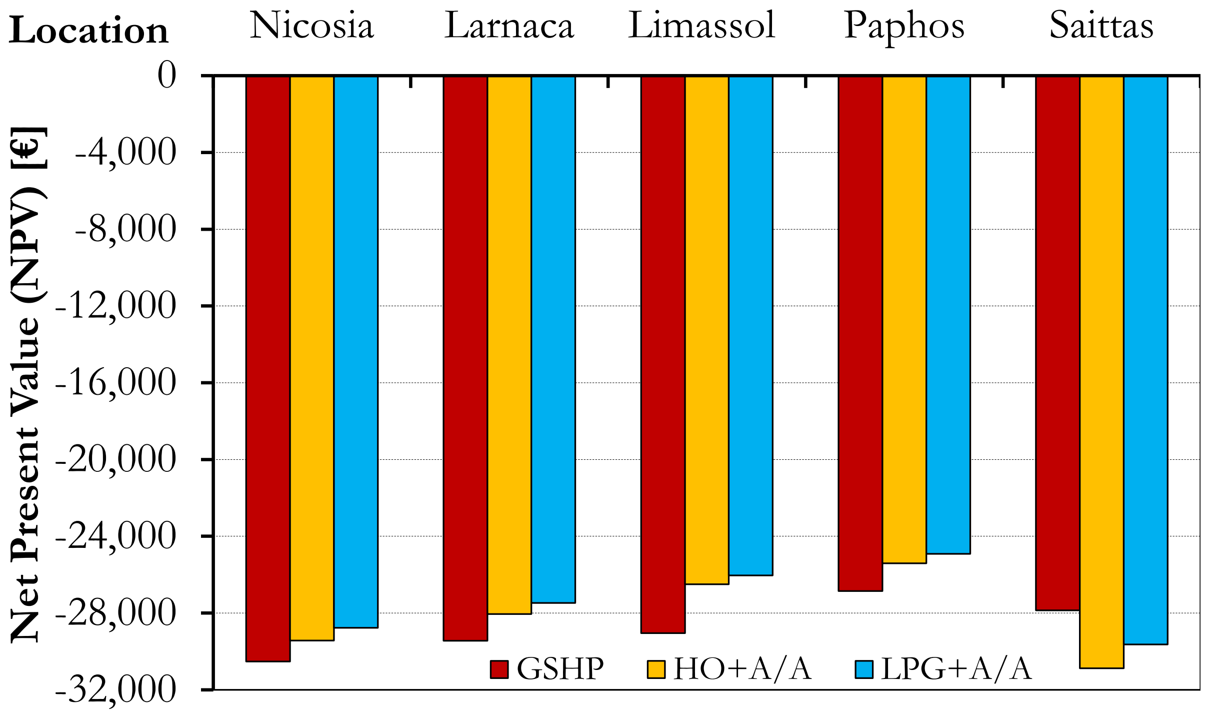
# Energy, Environmental and Economic Analysis – Single-family building

Single-family building – Economic evaluation

In mainland and southern areas: 3,000 € - 1,090 € higher

In northern areas: 3,050 € - 1,785 € lower

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# Optimization of the energy behavior of the building envelope

Energy improvement interventions on the buildings' envelope:

- Enhancement of the opaque envelope
  - Thermal insulation
- Enhancement of the glazing envelope
  - Enhance the thermal characteristics of the openings' frame and glass
- Minimization of solar thermal gains
  - External shading
- Free cooling

The optimum level of each intervention has been defined through a lifecycle cost analysis taking into consideration Regulation 244/2012/EC

# Enhancement of the opaque envelope – Thermal Insulation

| Scenario | Building Element | | | | |
|---|---|---|---|---|---|
| | Reinforce Concrete | Masonry | Roof | Floor above Ground | Pilotis |
| | Thermal transmittance of the building elements (U – [W/(m$^2$·K)]) | | | | |
| Baseline | 0.69 | 0.59 | 0.61 | 3.28 | 0.59 |
| SBE1 | 0.61 | 0.49 | 0.50 | 0.77 | 0.49 |
| SBE2 | 0.51 | 0.42 | 0.43 | 0.50 | 0.42 |
| SBE3 | 0.44 | 0.37 | 0.38 | 0.43 | 0.37 |
| SBE4 | 0.38 | 0.33 | 0.34 | 0.38 | 0.33 |
| SBE5 | 0.34 | 0.30 | 0.30 | 0.34 | 0.30 |
| SBE6 | 0.30 | - | 0.27 | 0.30 | 0.27 |
| SBE7 | 0.28 | - | 0.25 | 0.28 | 0.25 |
| SBE8 | 0.25 | - | 0.23 | 0.25 | 0.23 |
| SBE9 | - | - | 0.22 | 0.23 | - |
| SBE10 | - | - | - | 0.22 | - |
| SBE11 | - | - | - | 0.20 | - |

# Enhancement of the glazing envelope

| Scenario | Thermal transmittance of the window frame ($U_f$ – [W/(m$^2$·K)]) | Thermal transmittance of the window glass ($U_g$ – [W/(m$^2$·K)]) | Solar factor ($g_w$) |
|---|---|---|---|
| Baseline | 2.8 | 2.8 | 0.78 |
| SW1 | 2.0 | 1.6 | 0.54 |
| SW2 | 2.0 | 1.6 | 0.34 |
| SW3 | 2.0 | 1.4 | 0.2 |
| SW4 | 1.6 | 1.6 | 0.54 |
| SW5 | 1.6 | 1.6 | 0.34 |
| SW6 | 1.4 | 1.6 | 0.54 |
| SW7 | 1.4 | 1.6 | 0.34 |
| SW8 | 1.0 | 1.6 | 0.54 |
| SW9 | 1.0 | 1.6 | 0.34 |

# External Shading: Horizontal overhang

| Scenario | Shading reduction factor |
|---|---|
| Baseline | 1.00 |
| SSO1 | 0.87 |
| SSO2 | 0.73 |
| SSO3 | 0.58 |
| SSO4 | 0.44 |

# Free Cooling

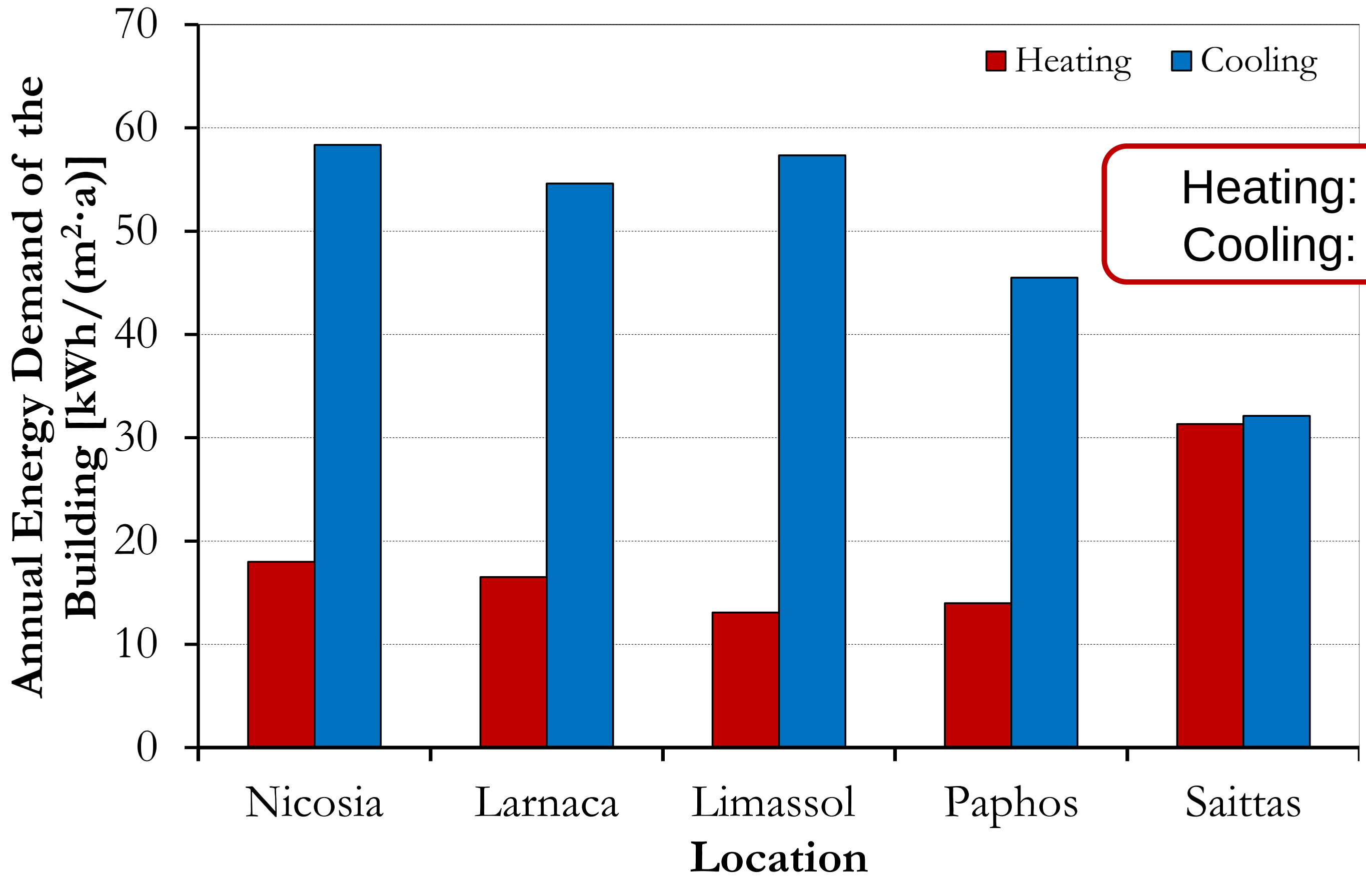
| Scenario | Opening percentage |
| --- | --- |
| Baseline | - |
| SFC1 | 25% |
| SFC2 | 50% |
| SFC3 | 75% |
| SFC4 | 100% |

# Characteristics of the low energy single-family building (NZEB)

| Building Element | Location | | | | |
|---|---|---|---|---|---|
| | Nicosia | Larnaca | Limassol | Paphos | Saittas |
| Thermal transmittance of the opaque envelope [W/(m$^2$·K)] | 0.42 | 0.42 | 0.42 | 0.42 | 0.36 |
| Thermal transmittance of the ground floor [W/(m$^2$·K)] | 0.34 | 0.38 | 0.38 | 0.38 | 0.25 |
| Thermal transmittance of the roof [W/(m$^2$·K)] | 0.30 | 0.34 | 0.34 | 0.34 | 0.25 |
| Shading redaction factor | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Thermal properties of the window elements [$U_f$ / $U_g$ / $g_w$] | 2.0 / 1.6 / 0.54 | 2.0 / 1.6 / 0.54 | 2.0 / 1.6 / 0.54 | 2.0 / 1.6 / 0.54 | 2.0 / 1.6 / 0.54 |
| Natural ventilation – Windows' opening percentage | 100% | 100% | 100% | 100% | 100% |

# Energy demand of the NZEB single-family reference building

Single-family building, energy simulation results – NZEB



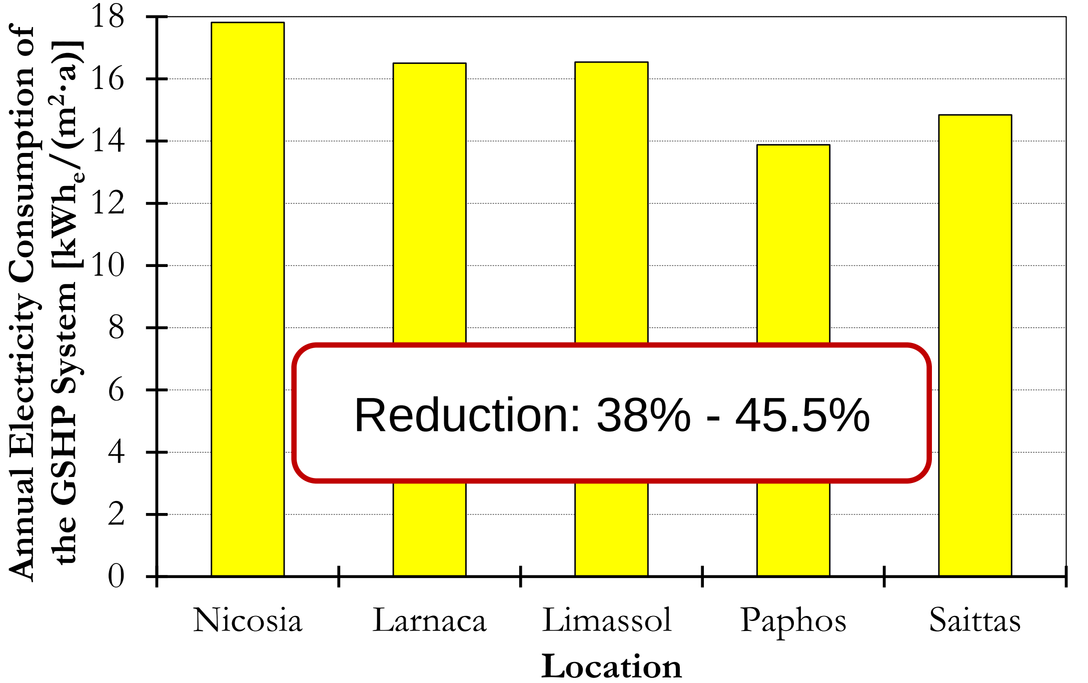

Heating: -26% to -34%
Cooling: -37% to -49%

# Design and simulation of the Ground Source Heat Pump system

Single-family building, design and simulation results – NZEB

Reduction: 29% - 33.5%

| Location | Boreholes x Length | Configuration |
|---|---|---|
| Nicosia | 2 x 92 m | Line: 1 x 2 |
| Larnaca | 2 x 89.5 m | Line: 1 x 2 |
| Limassol | 2 x 90.5 m | Line: 1 x 2 |
| Paphos | 2 x 72.5 m | Line: 1 x 2 |
| Saittas | 2 x 58.5 m | Line: 1 x 2 |

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# Energy, Environmental and Economic Analysis – Single-family building

Analysis of the **NZEB building**

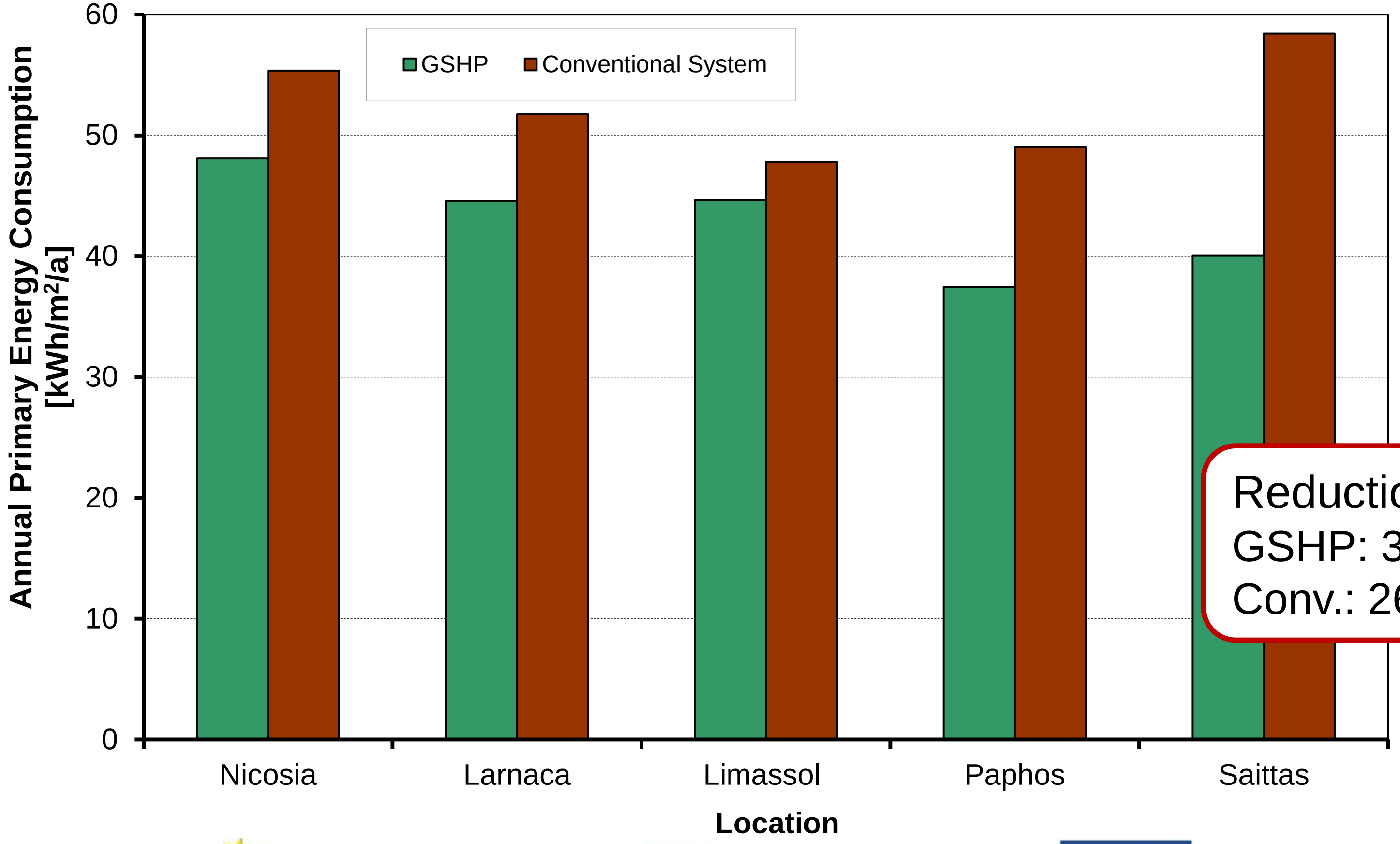
Conventional system:

- Oil-fired boiler and air-to-air-heat pump and
- LPG-fired boiler and air-to-air-heat pump and
  - Boiler efficiency: 0.92
- Heat pump:
  - Air-to-air split type
  - Analysis on an hourly basis using:
    - Energy demand of the building envelope,
    - Ambient temperature retrieved from Meteonorm database
    - EER provided by HP manufacturer

# Energy, Environmental and Economic Analysis – Single-family building

## NZEB Single-family building – Energy evaluation

6.5% - 31.5% less




Reduction
GSHP: 37.5% - 45.5%
Conv.: 26.5% - 39%

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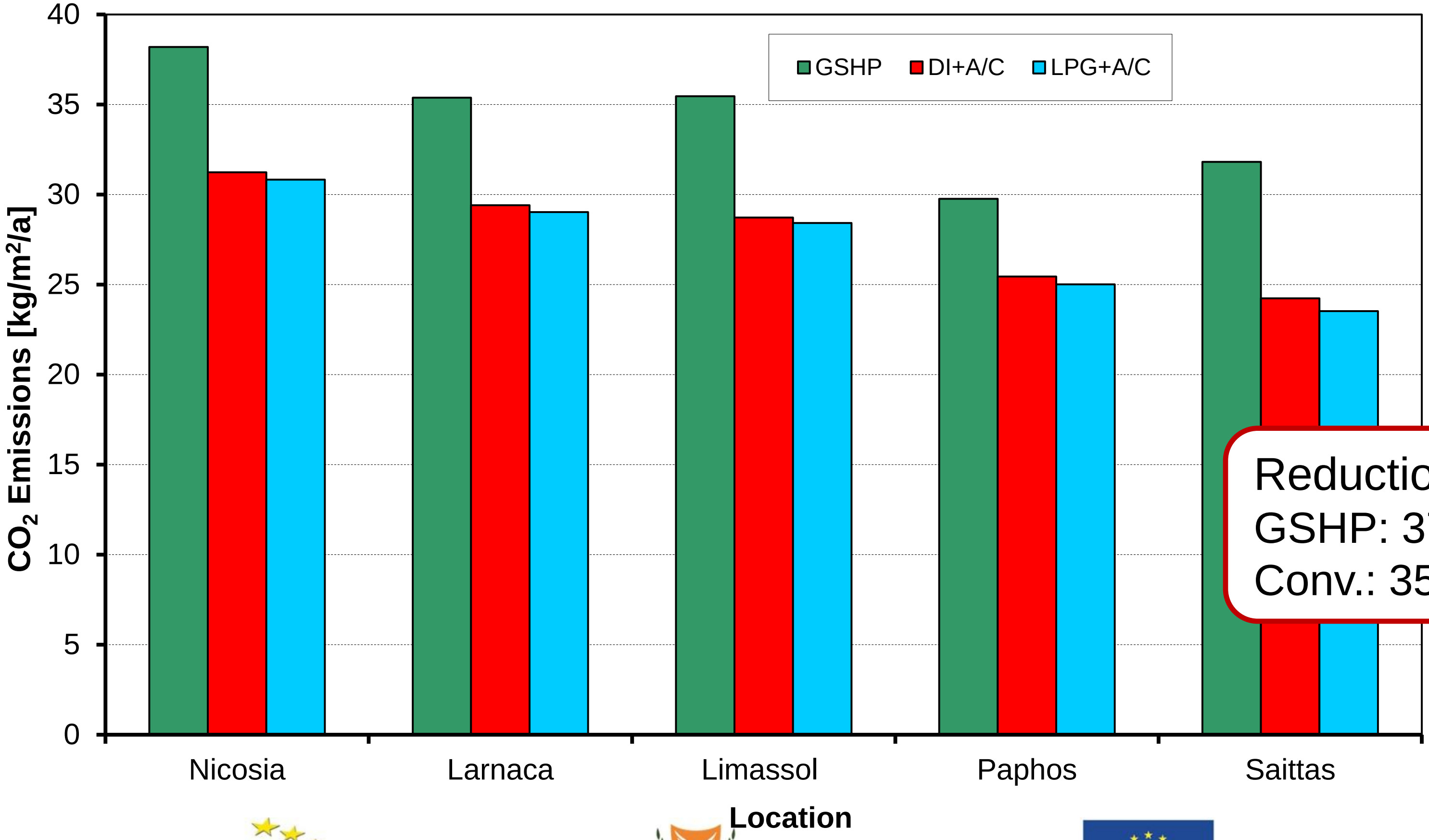
# Energy, Environmental and Economic Analysis – Single-family building

NZEB Single-family building – Environmental evaluation

14.5% - 26.0% higher




Reduction
GSHP: 37.5% - 45.5%
Conv.: 35.3% - 43.2%

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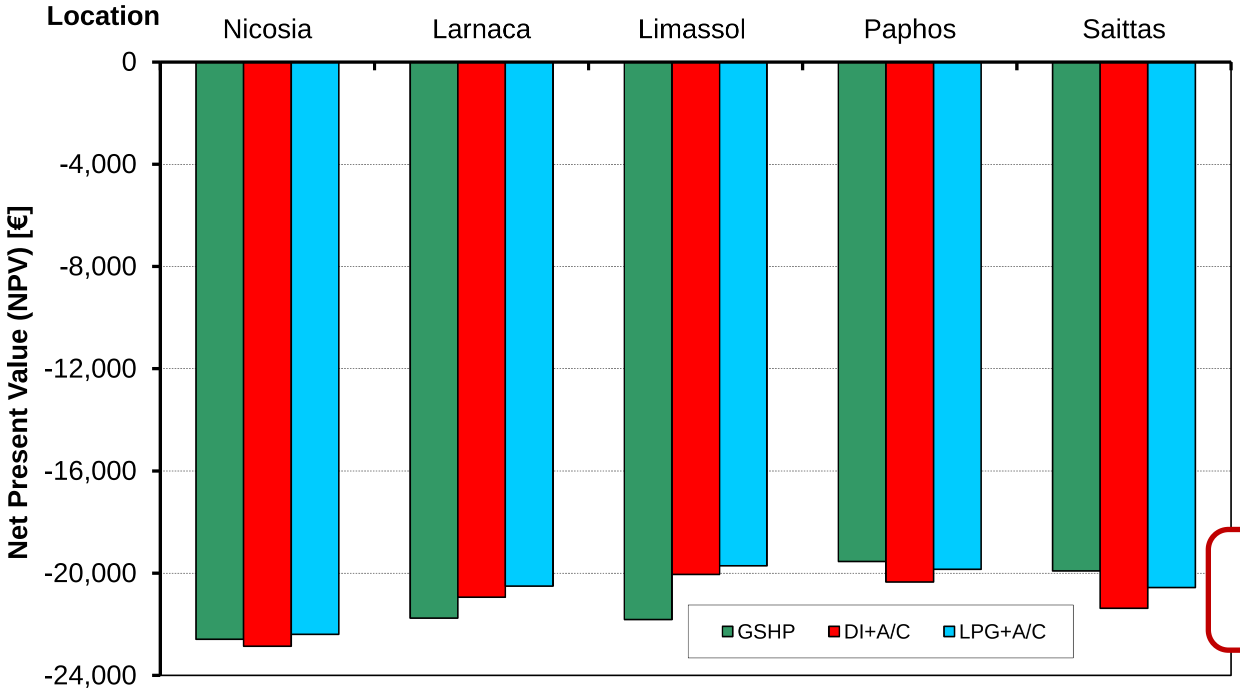
# Energy, Environmental and Economic Analysis – Single-family building

NZEB Single-family building – Economic evaluation

In Larnaca & Limassol: 2,150 € - 850 € higher

In other areas: 1,500 € - 300 € lower




Reduction: 20% - 24%

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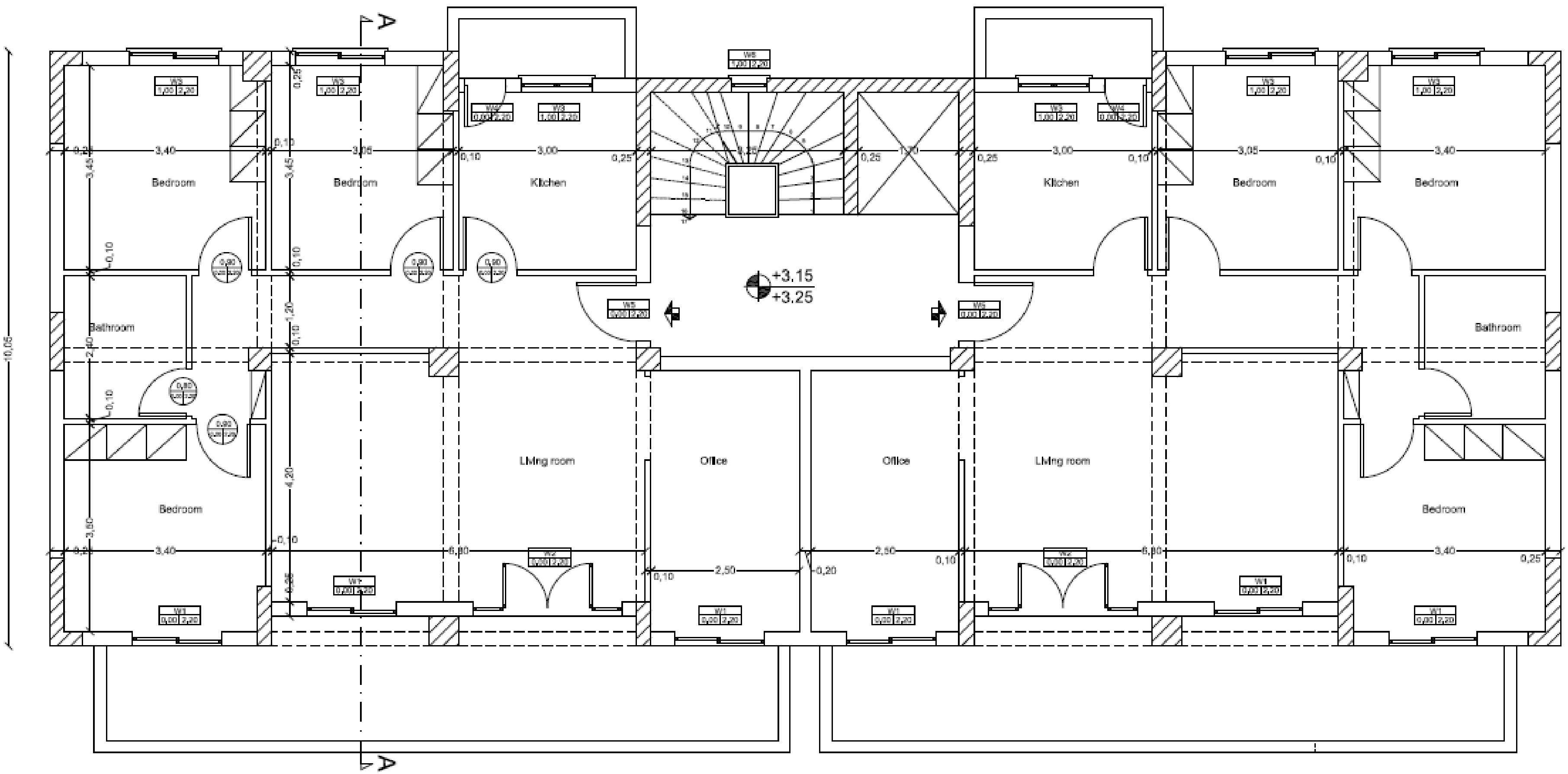
# Architectural plan of the multi-family reference building

Multi-family house – Typical floor (4 levels – 867.8 m$^2$)

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# Geometrical model of the multi-family reference building

Multi-family house

# Thermal characteristics of the multi-family reference building

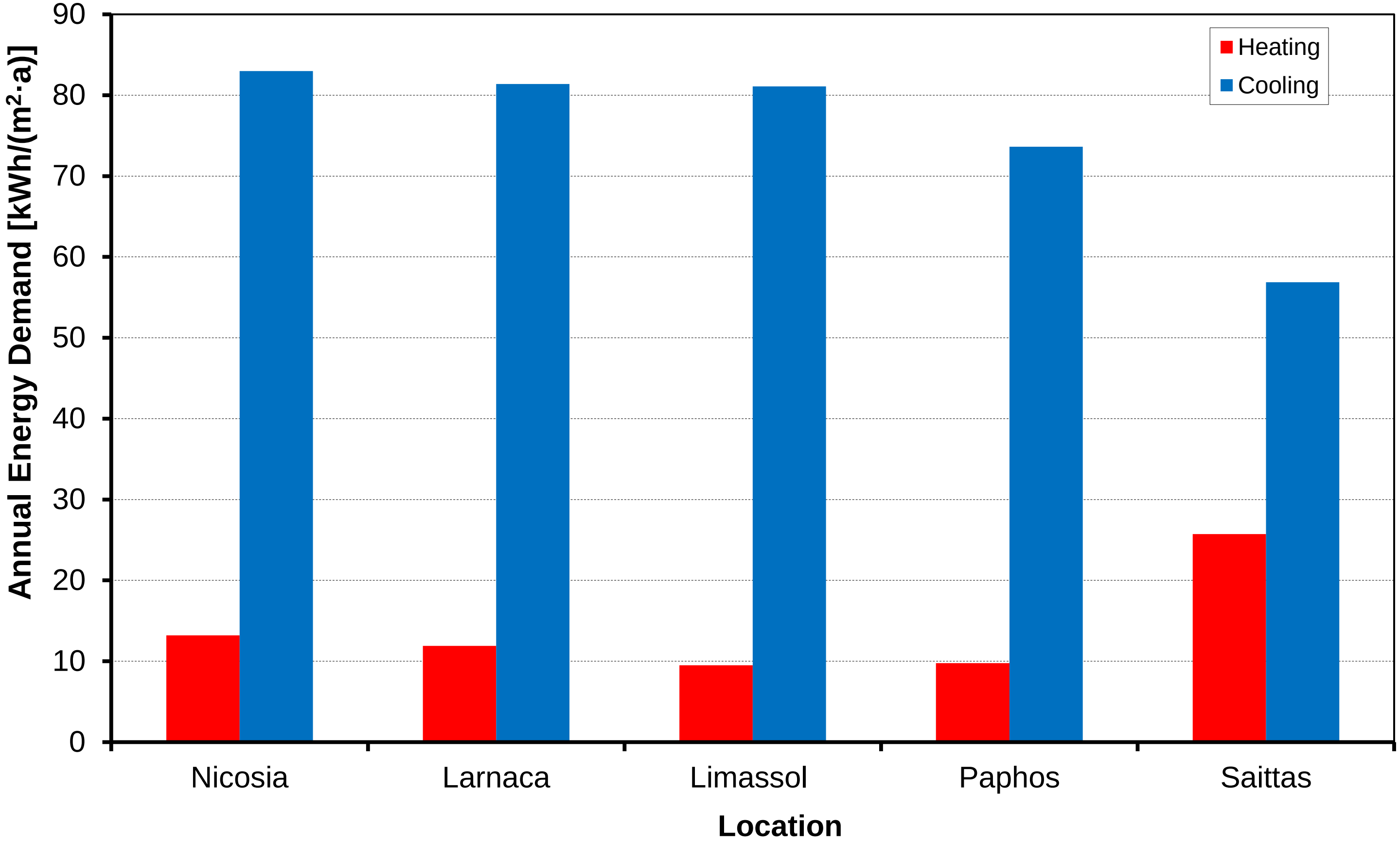
Current practice: In compliance with current Regulations of Energy Efficiency

| Building Element | Thermal Transmittance U [W/(m²·K)] | |
|---|---|---|
| | Case Study | ΚΔΠ 432/2013 |
| Masonry | 0,58 | 0,72 |
| Reinforce Concrete | 0,65 | 0,72 |
| Roof | 0,61 | 0,63 |
| Pilotis | 0,59 | 0,63 |
| Openings | $(U_f/U_g)$: (2,8/2,8) | $U_w$: 3,23 |

The energy demand of the multi-family reference building was calculated on an hourly basis with the aid of EnergyPlus software in 5 representative locations of Cyprus

# Energy demand of the multi-family reference building

Multi-family building, energy simulation results – Current practice

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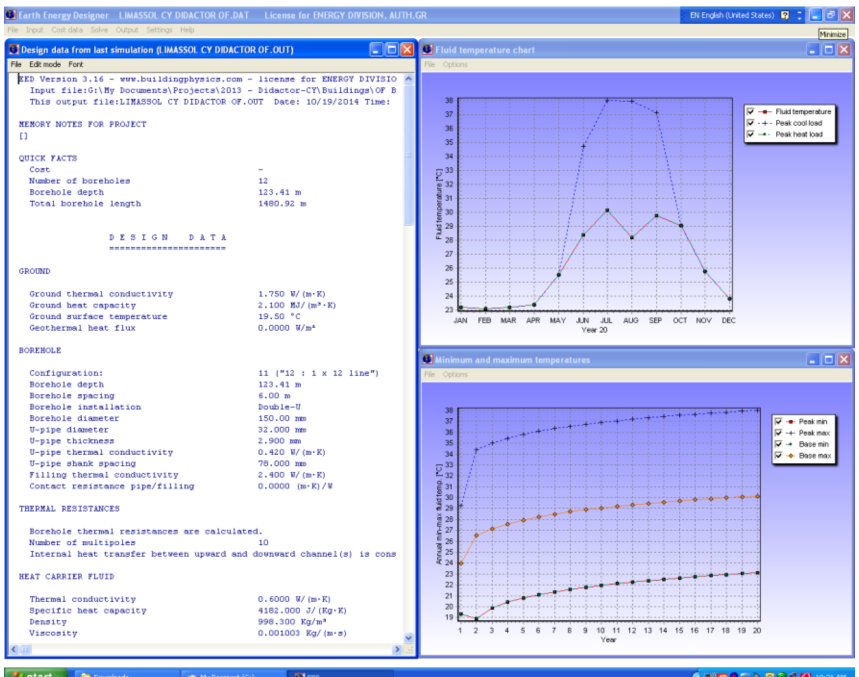


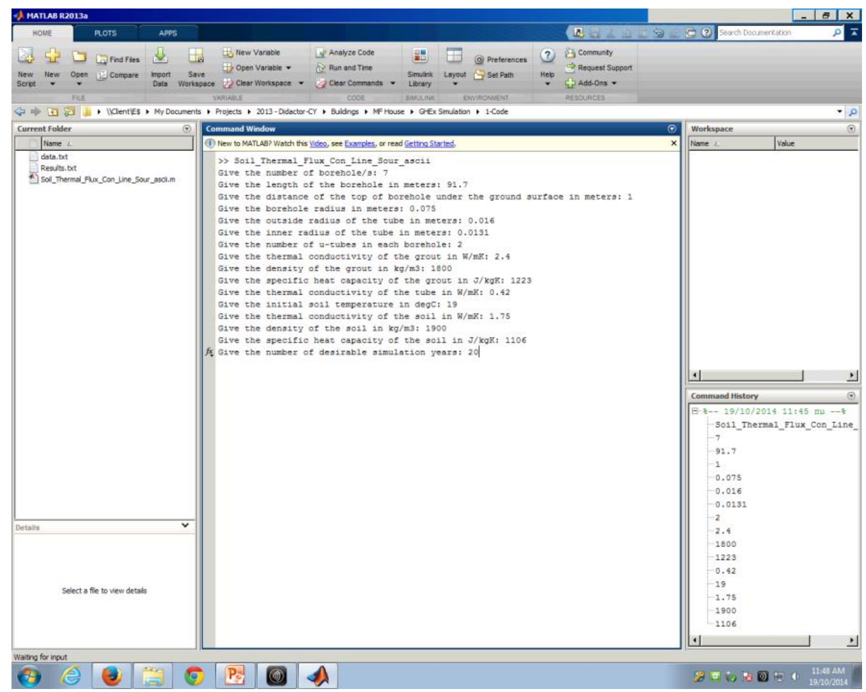


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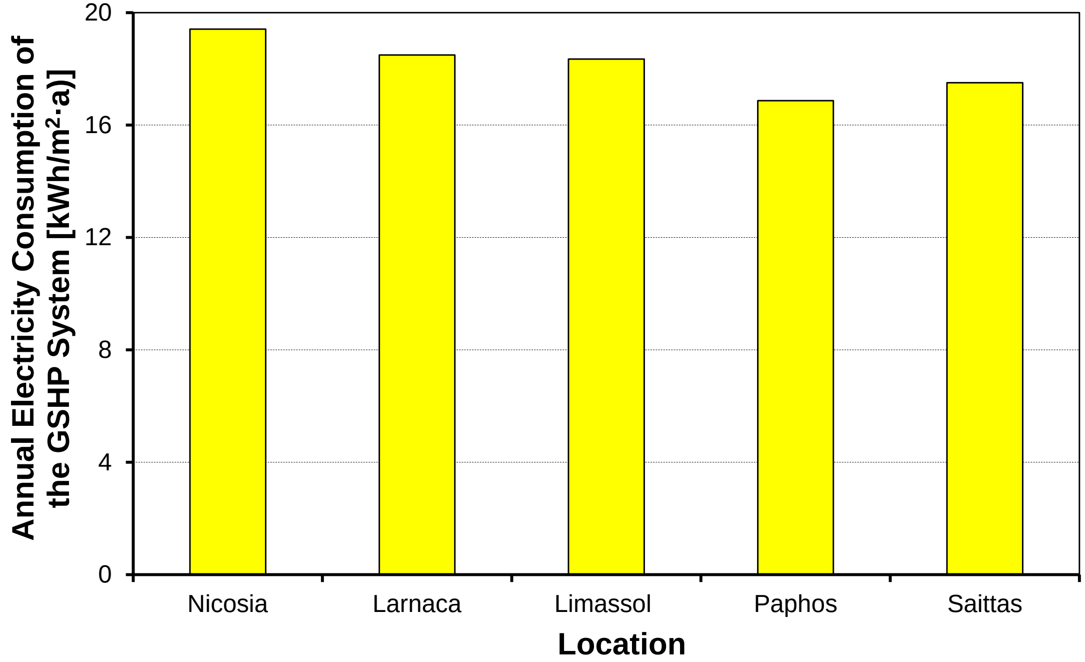
# Design and simulation of the Ground Source Heat Pump system

Multi-family building, design and simulation results – Current practice

| Location | Boreholes x Length | Configuration |
|---|---|---|
| Nicosia | 9 x 118 m | Line: 1 X 9 |
| Larnaca | 10 x 112.5 m | Line: 1 X 10 |
| Limassol | 9 x 120 m | Line: 1 X 9 |
| Paphos | 8 x 112 m | Line: 1 X 8 |
| Saittas | 5 x 118 m | Line: 1 x 5 |

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# Energy, Environmental and Economic Analysis – Multi-family building

Analysis of the **current building practice**

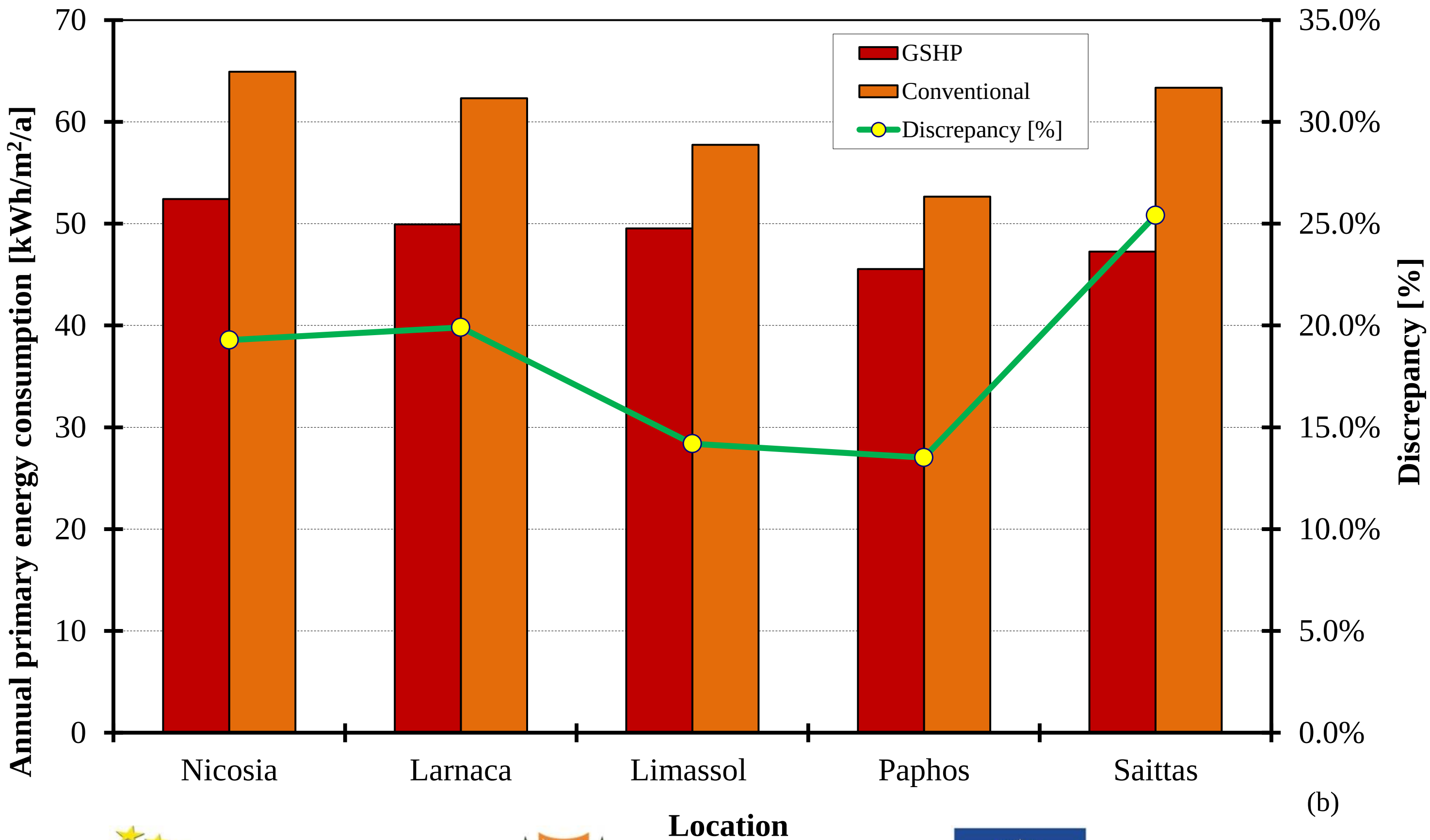
Conventional system:

- Oil-fired boiler and air-to-air-heat pump and
- LPG-fired boiler and air-to-air-heat pump and
  - Boiler efficiency: 0.92
- Heat pump:
  - Air-to-air split type
  - Analysis on an hourly base using:
    - Energy demand of the building envelope,
    - Ambient temperature retrieved from Meteonorm database
    - EER provided by HP manufacturer

# Energy, Environmental and Economic Analysis – Multi-family building

Multi-family building – Energy evaluation – Preliminary results

13.5% - 25.4% less

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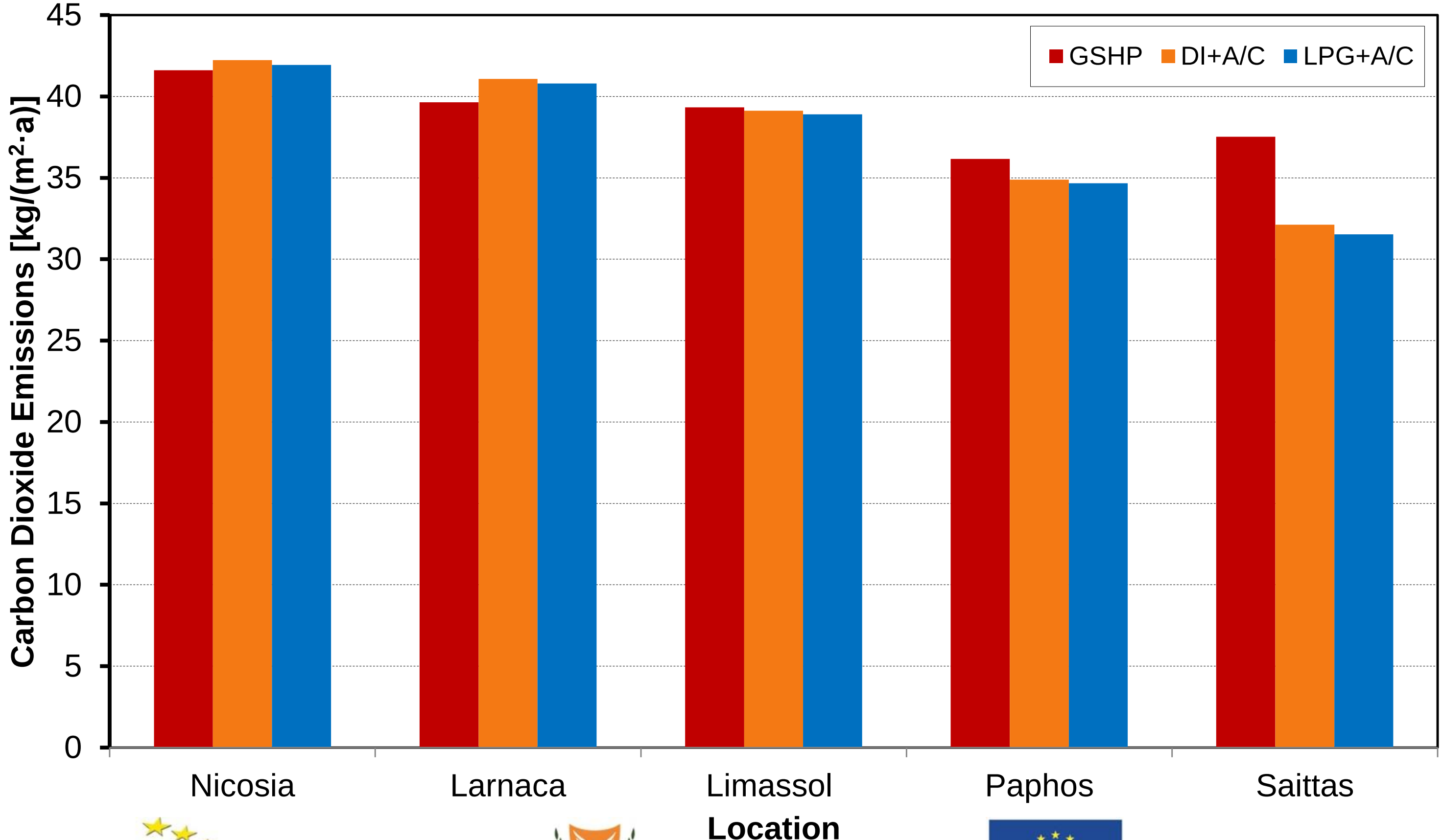
# Energy, Environmental and Economic Analysis – Multi-family building

Multi-family building – Environmental evaluation – Preliminary results

-0.8% to 16.0% higher

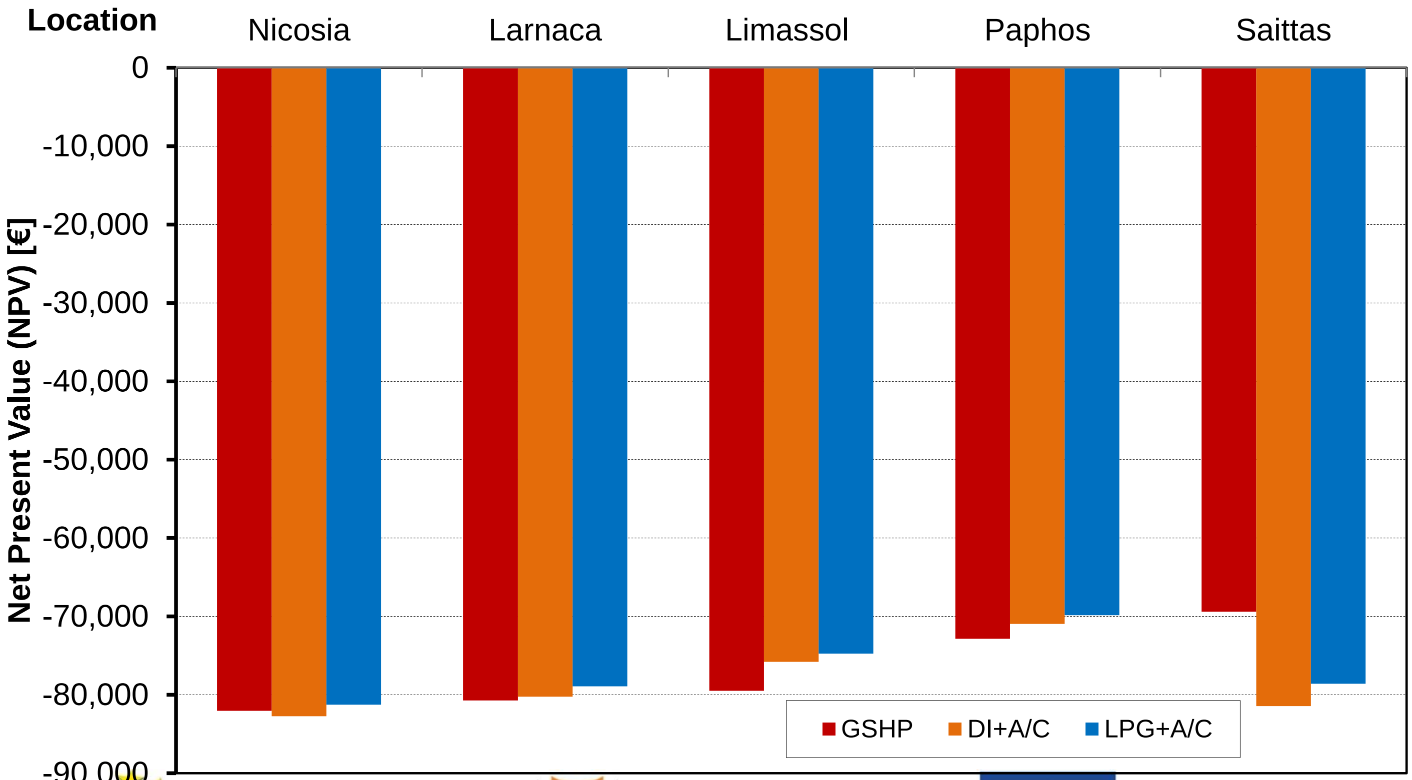


# Energy, Environmental and Economic Analysis – Multi-family building

Multi-family building – Economic evaluation – Preliminary results

In southern areas: 480 € - 4,760 € higher

In mainland and northern areas: 710 € - 12,065 € lower

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# Optimization of the energy behavior of the building envelope

Energy improvement interventions on the buildings' envelope:

- Enhancement of the opaque envelope
  - Thermal insulation
- Enhancement of the glazing envelope
  - Enhance the thermal characteristics of the openings' frame and glass
- Minimization of solar thermal gains
  - External shading
- Free cooling

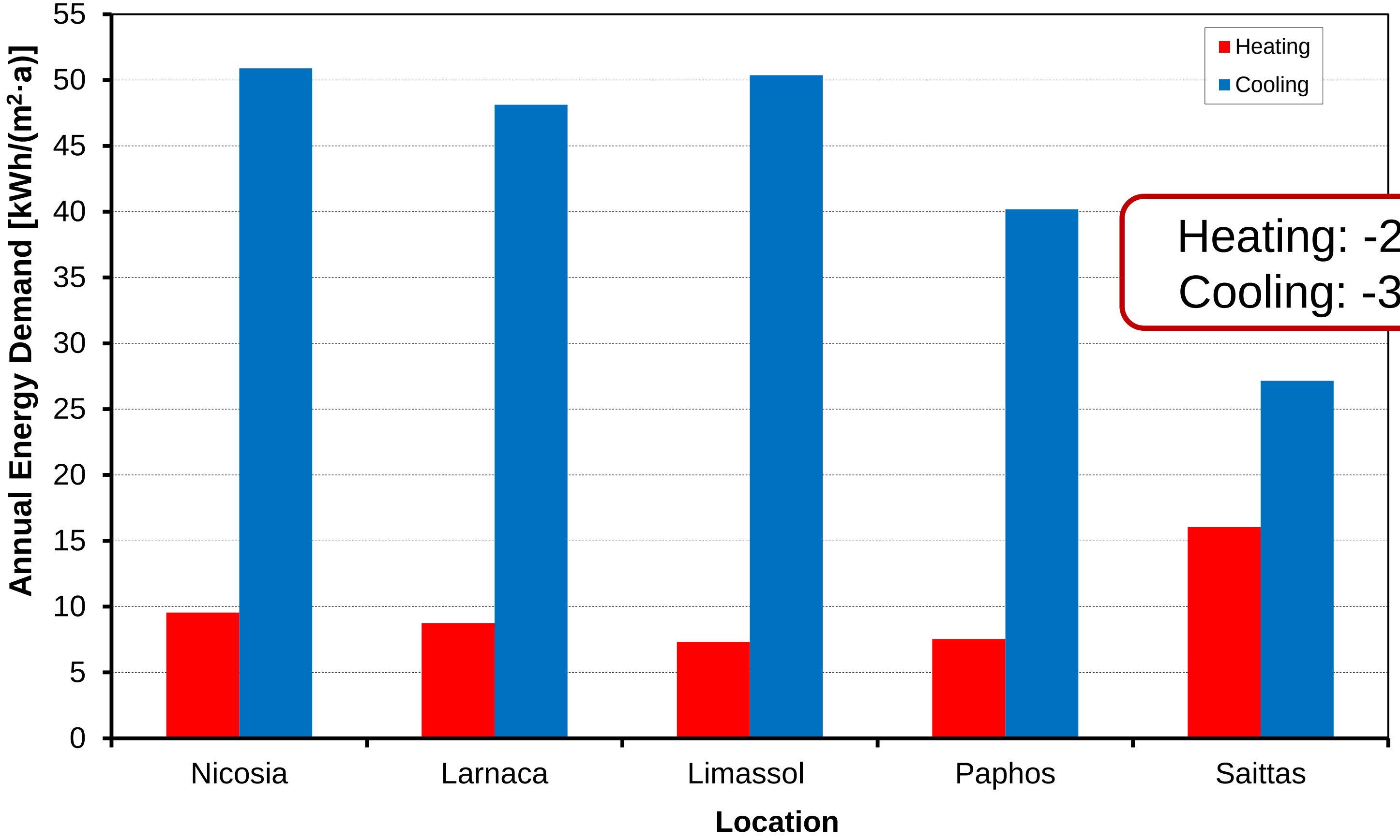
The optimum level of each intervention has been defined through a lifecycle cost analysis taking into consideration Regulation 244/2012/EC

# Characteristics of the low energy multi-family building (NZEB)

| Building Element | Location | | | | |
|---|---|---|---|---|---|
| | Nicosia | Larnaca | Limassol | Paphos | Saittas |
| Thermal transmittance of the vertical opaque envelope [W/(m$^2$·K)] | 0.42 | 0.42 | 0.42 | 0.42 | 0.33 |
| Thermal transmittance of pilotis [W/(m$^2$·K)] | 0.37 | 0.42 | 0.49 | 0.49 | 0.27 |
| Thermal transmittance of the roof [W/(m$^2$·K)] | 0.34 | 0.34 | 0.38 | 0.38 | 0.25 |
| Shading redaction factor | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Thermal properties of the window elements [$U_f$ / $U_g$ / $g_w$] | 2.0 / 1.6 / 0.54 | 2.0 / 1.6 / 0.54 | 2.0 / 1.6 / 0.54 | 2.0 / 1.6 / 0.54 | 2.0 / 1.6 / 0.54 |
| Natural ventilation – Windows' opening percentage | 100% | 100% | 100% | 100% | 100% |

# Energy demand of the NZEB Multi-family reference building

Multi-family building, energy simulation results – NZEB



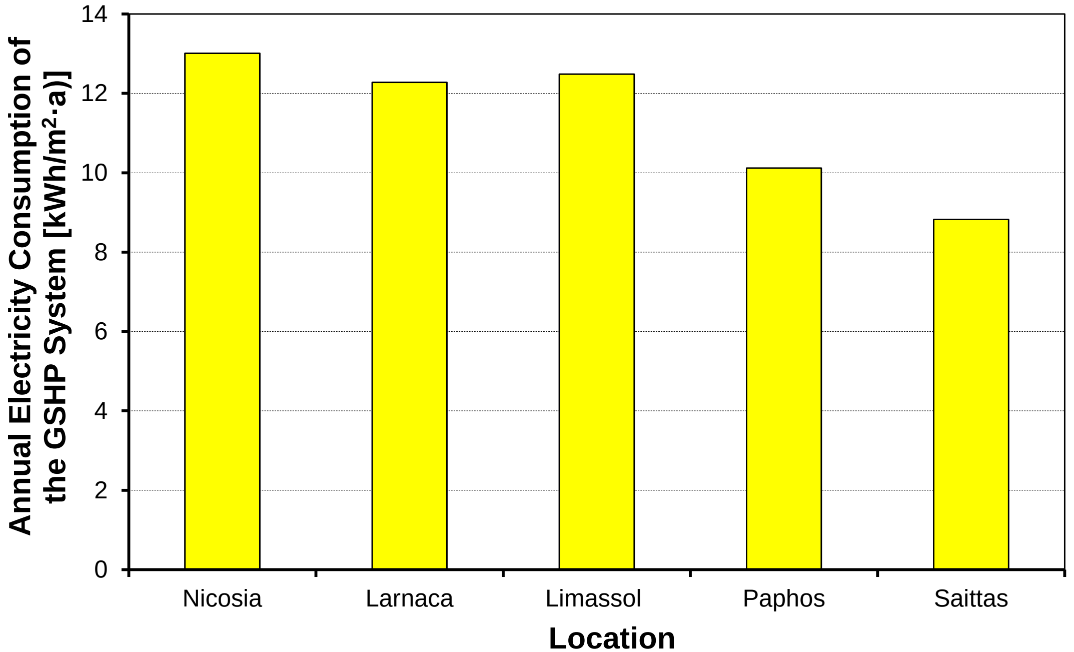

Heating: -23% to -37.5%
Cooling: -38% to -52.5%

# Design and simulation of the Ground Source Heat Pump system

Multi-family building, design and simulation results – NZEB

Reduction: 25% - 43%

| Location | Boreholes x Length | Configuration |
|---|---|---|
| Nicosia | 6 x 111 m | Line: 1 x 6 |
| Larnaca | 6 x 106.5 m | Line: 1 x 6 |
| Limassol | 6 x 112.5 m | Line: 1 x 6 |
| Paphos | 5 x 116 m | Line: 1 x 5 |
| Saittas | 7 x 63 m | Line: 1 x 7 |




Reduction: 32% - 50%

# Energy, Environmental and Economic Analysis – Multi-family building

Analysis of the **NZEB building**

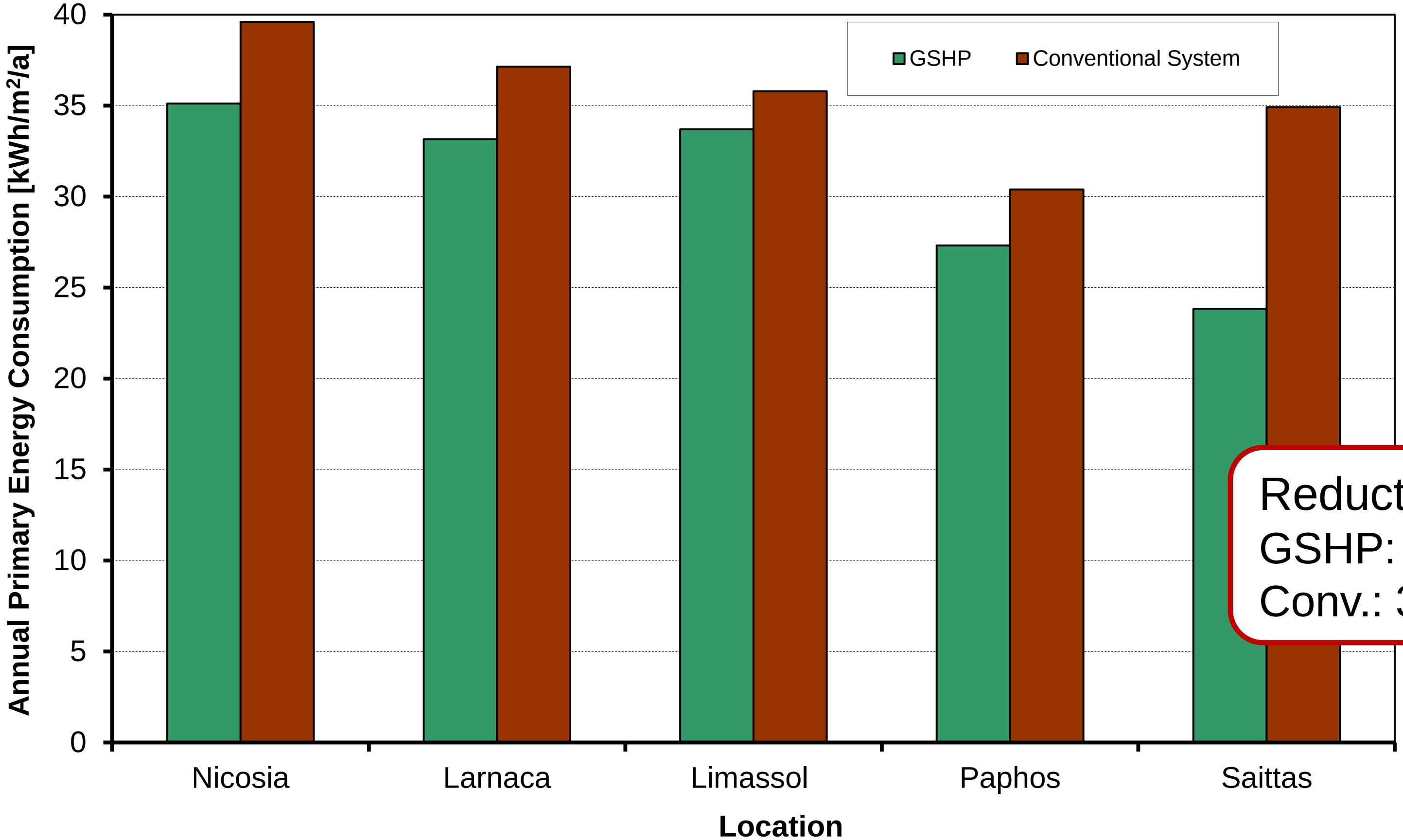
Conventional system:

- Oil-fired boiler and air-to-air-heat pump and
- LPG-fired boiler and air-to-air-heat pump and
  - Boiler efficiency: 0.92
- Heat pump:
  - Air-to-air split type
  - Analysis on an hourly basis using:
    - Energy demand of the building envelope,
    - Ambient temperature retrieved from Meteonorm database
    - EER provided by HP manufacturer

# Energy, Environmental and Economic Analysis – Multi-family building

NZEB Multi-family building – Energy evaluation

6% - 32% less




Reduction
GSHP: 32% - 49.5%
Conv.: 38% - 45%

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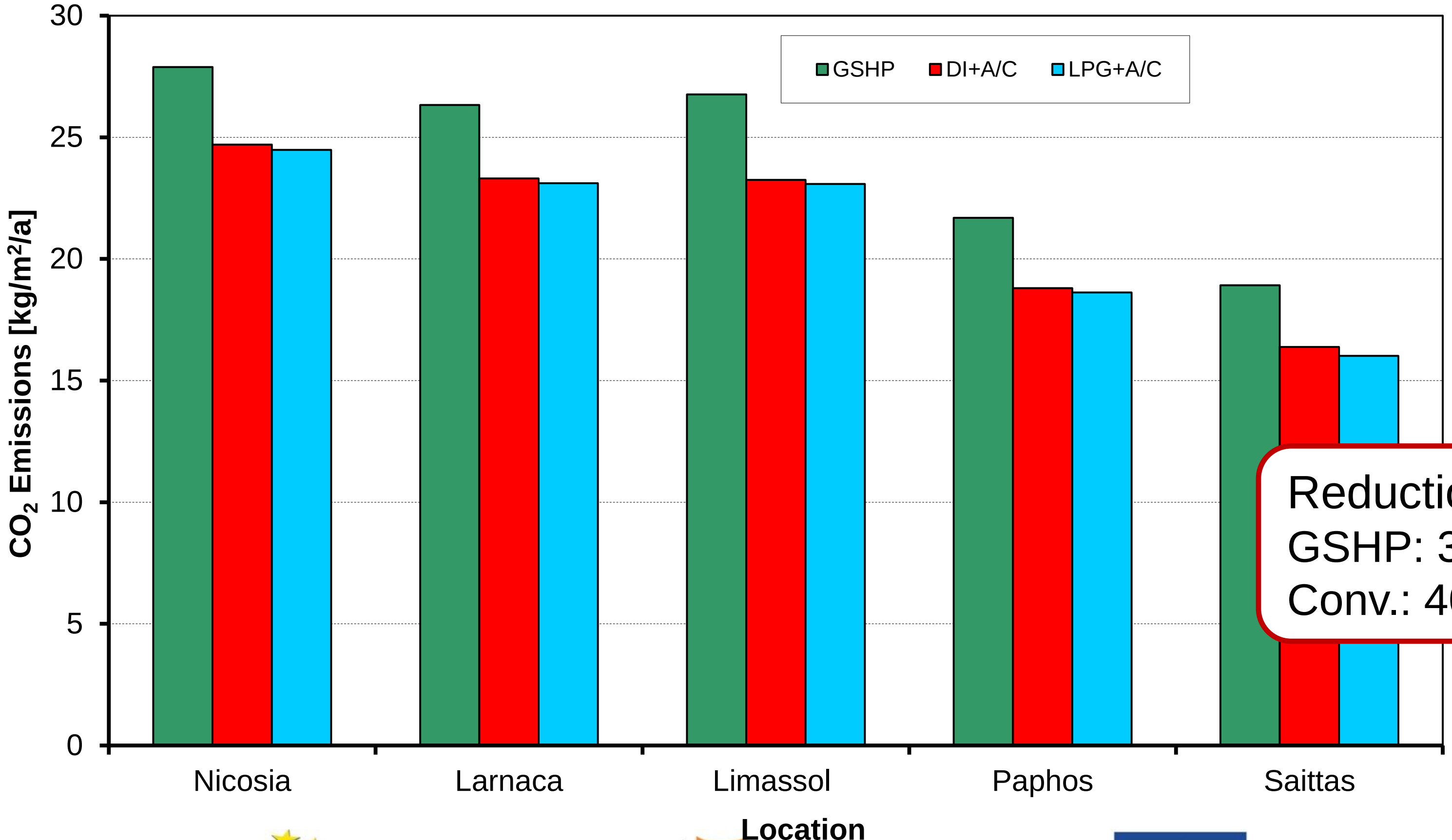
# Energy, Environmental and Economic Analysis – Multi-family building

NZEB Multi-family building – Environmental evaluation

11.5% - 15.3% higher




Reduction
GSHP: 32% - 49.5%
Conv.: 40.5% - 49.2%

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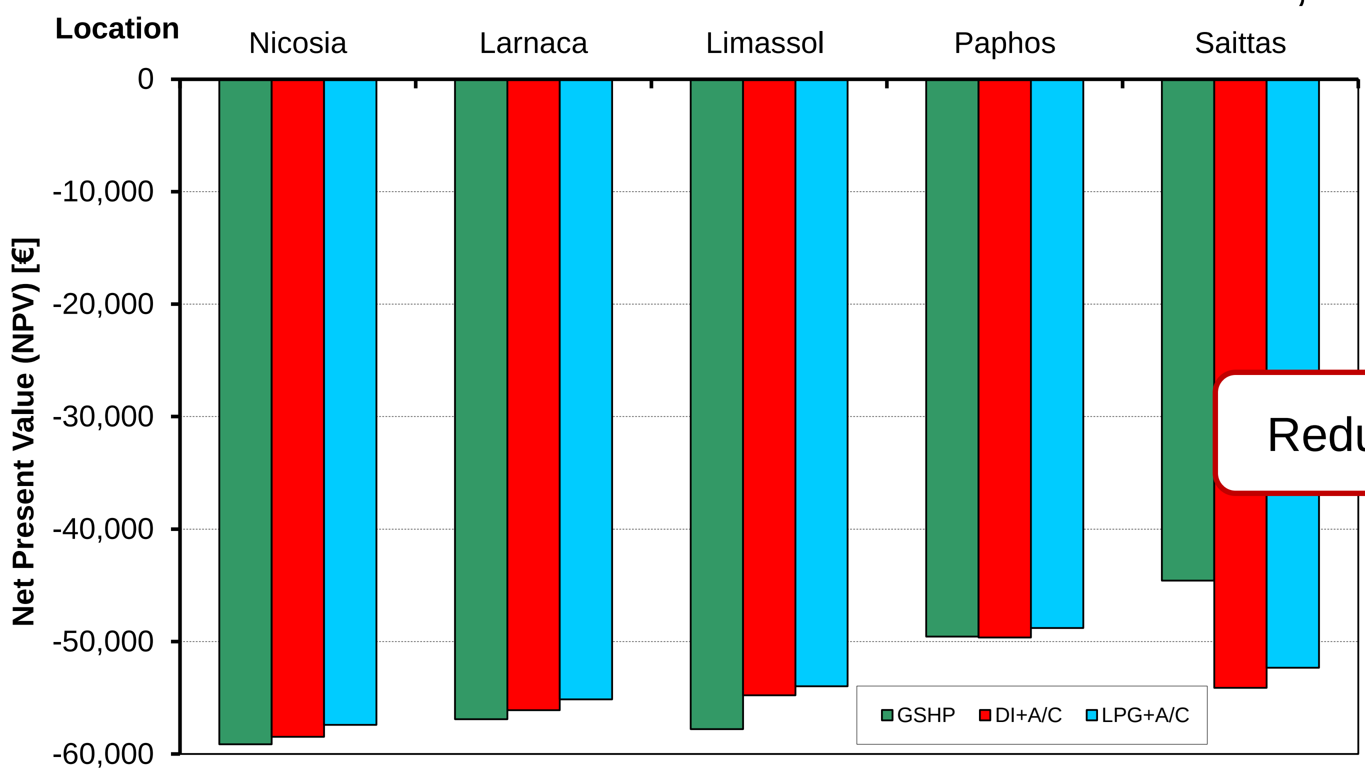
# Energy, Environmental and Economic Analysis – Multi-family building

NZEB Multi-family building – Economic evaluation

In Saittas: 7,800 € - 9,500 € lower

In other areas: 3,800 € - ~0 € higher




Reduction: 27% - 35.8%

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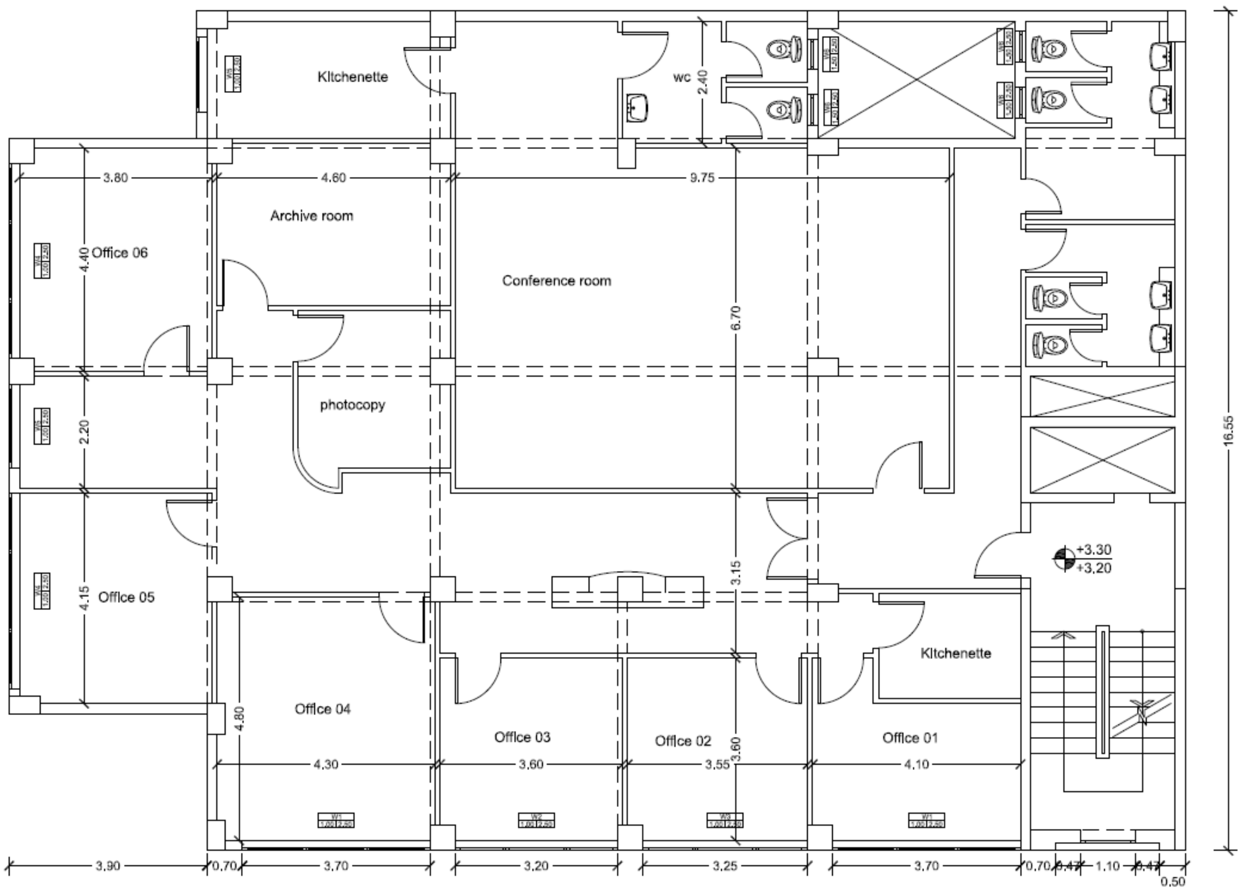
# Architectural plan of the office reference building

Office Building – Typical floor




4 levels

1,350.2 m$^2$

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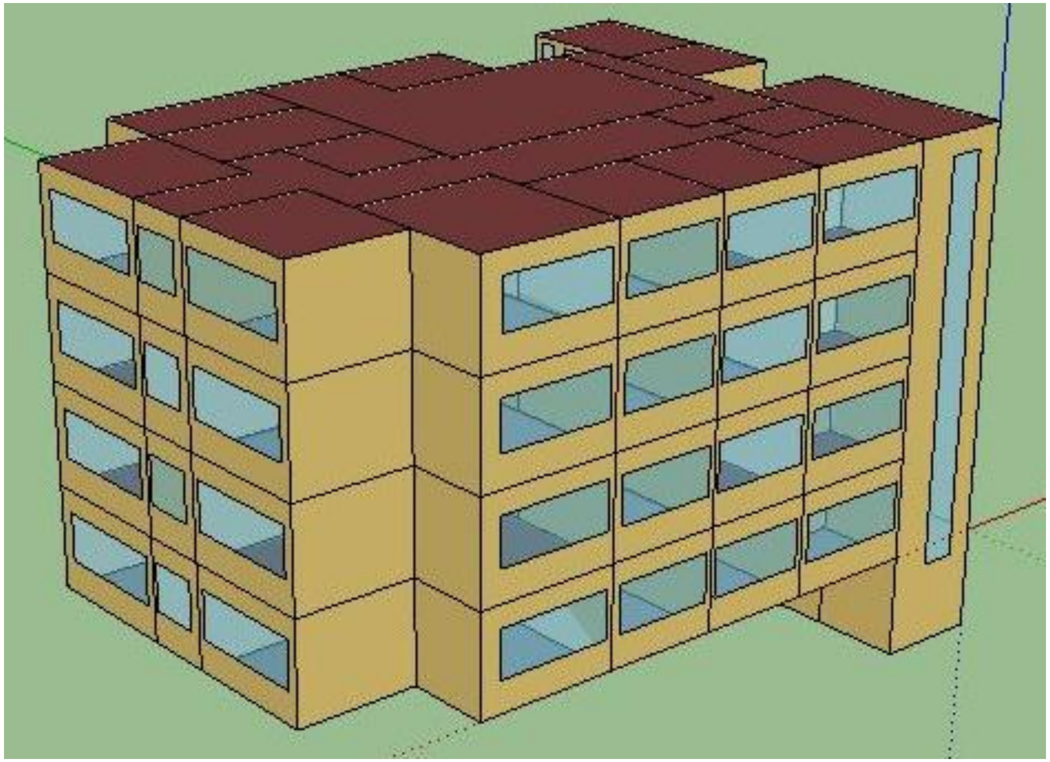
# Geometrical model of office reference building

Office Building



# Thermal characteristics of office reference building

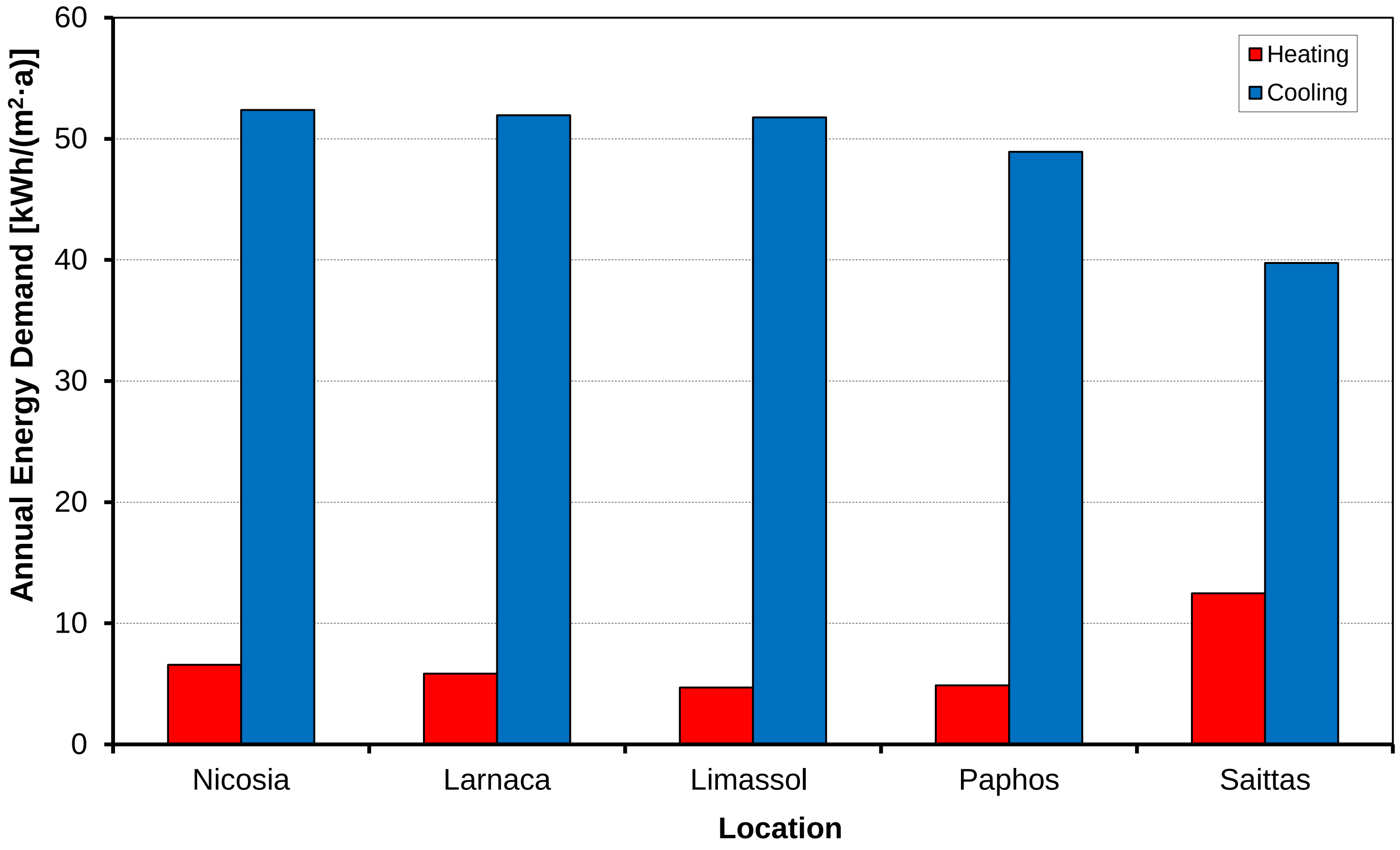
Current practice: In compliance with current Regulations of Energy Efficiency

| Building Element | Thermal Transmittance U [W/(m²·K)] | |
|---|---|---|
| | Case Study | ΚΔΠ 432/2013 |
| Masonry | 0,58 | 0,72 |
| Reinforce Concrete | 0,69 | 0,72 |
| Roof | 0,61 | 0,63 |
| Pilotis | 0,59 | 0,63 |
| Openings | $(U_f/U_g)$: (2,8/2,8) | $U_w$: 3,23 |

The energy demand of the single-family reference building was calculated on an hourly basis with the aid of EnergyPlus software in 5 representative locations of Cyprus

# Energy demand of the office reference building

Office building, energy simulation results – Current practice

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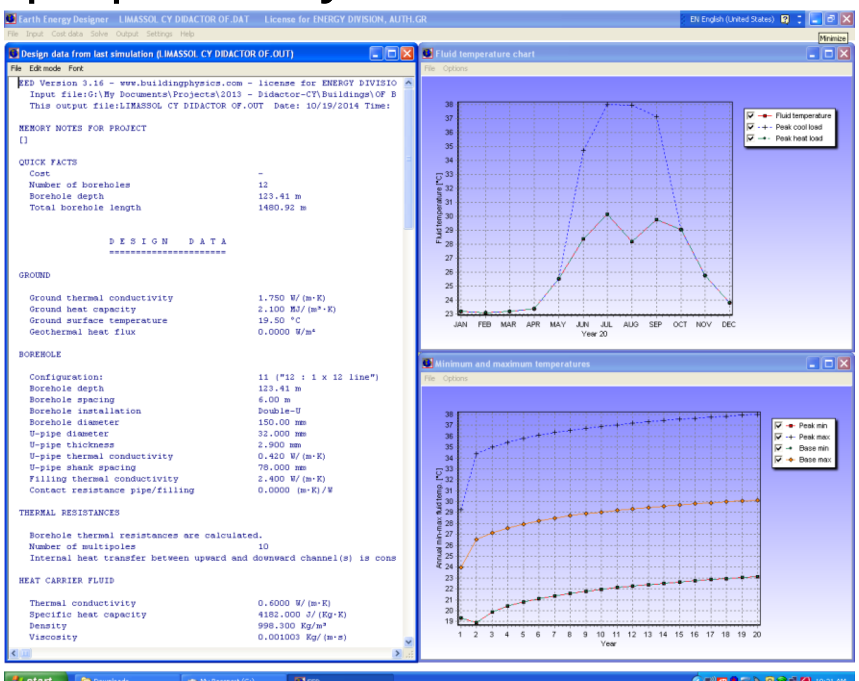
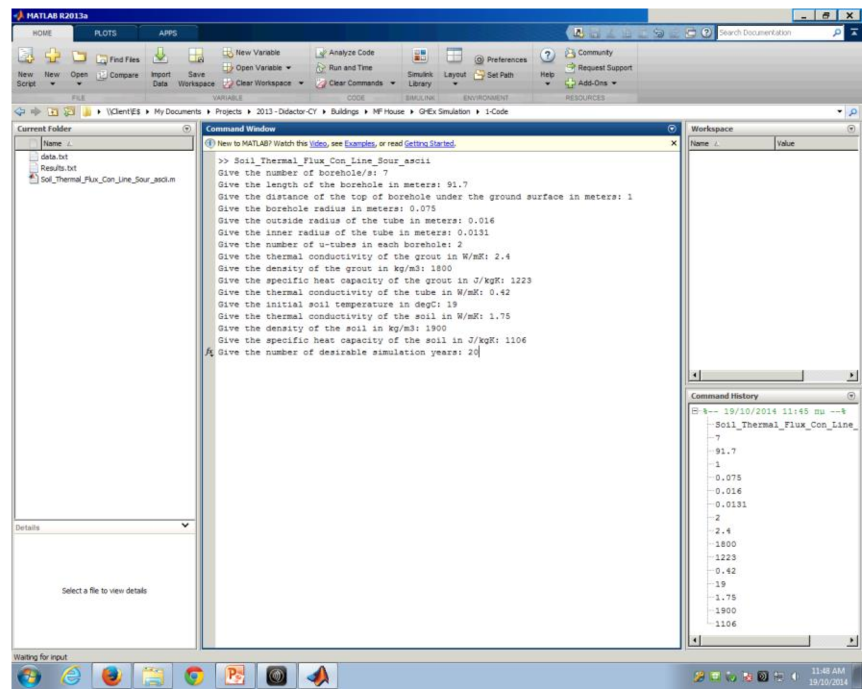
# Design and simulation of the Ground Source Heat Pump system

GSHP Design: EED 3.16

Energy consumption of the GHP: In-house software

Energy consumption of the circulation pump: Methodology proposed by Sfeir et al, 2005

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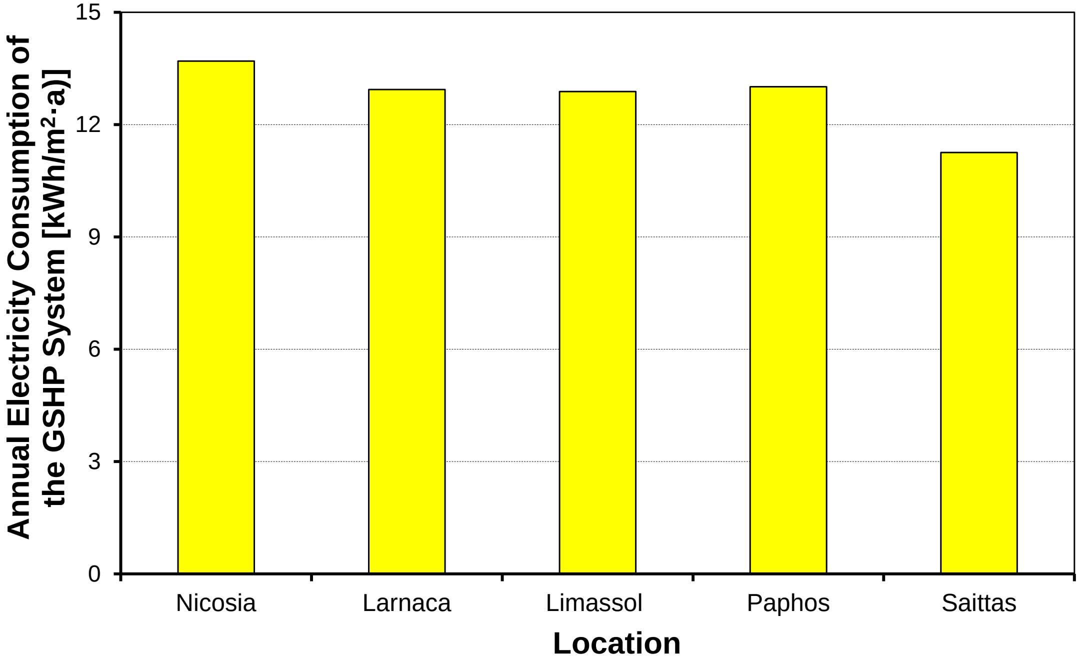
# Design and simulation of the Ground Source Heat Pump system

Office building, design and simulation results – Current practice

| Location | Boreholes x Length | Configuration |
|---|---|---|
| Nicosia | 12 x 120 m | Line: 1 X 12 |
| Larnaca | 12 x 126 m | Line: 1 X 12 |
| Limassol | 12 x 123 m | Line: 1 X 12 |
| Paphos | 10 x 118 m | Line: 1 X 10 |
| Saittas | 9 x 125 m | Line: 1 x 9 |



# Energy, Environmental and Economic Analysis – Office building

Analysis of the **current building practice**

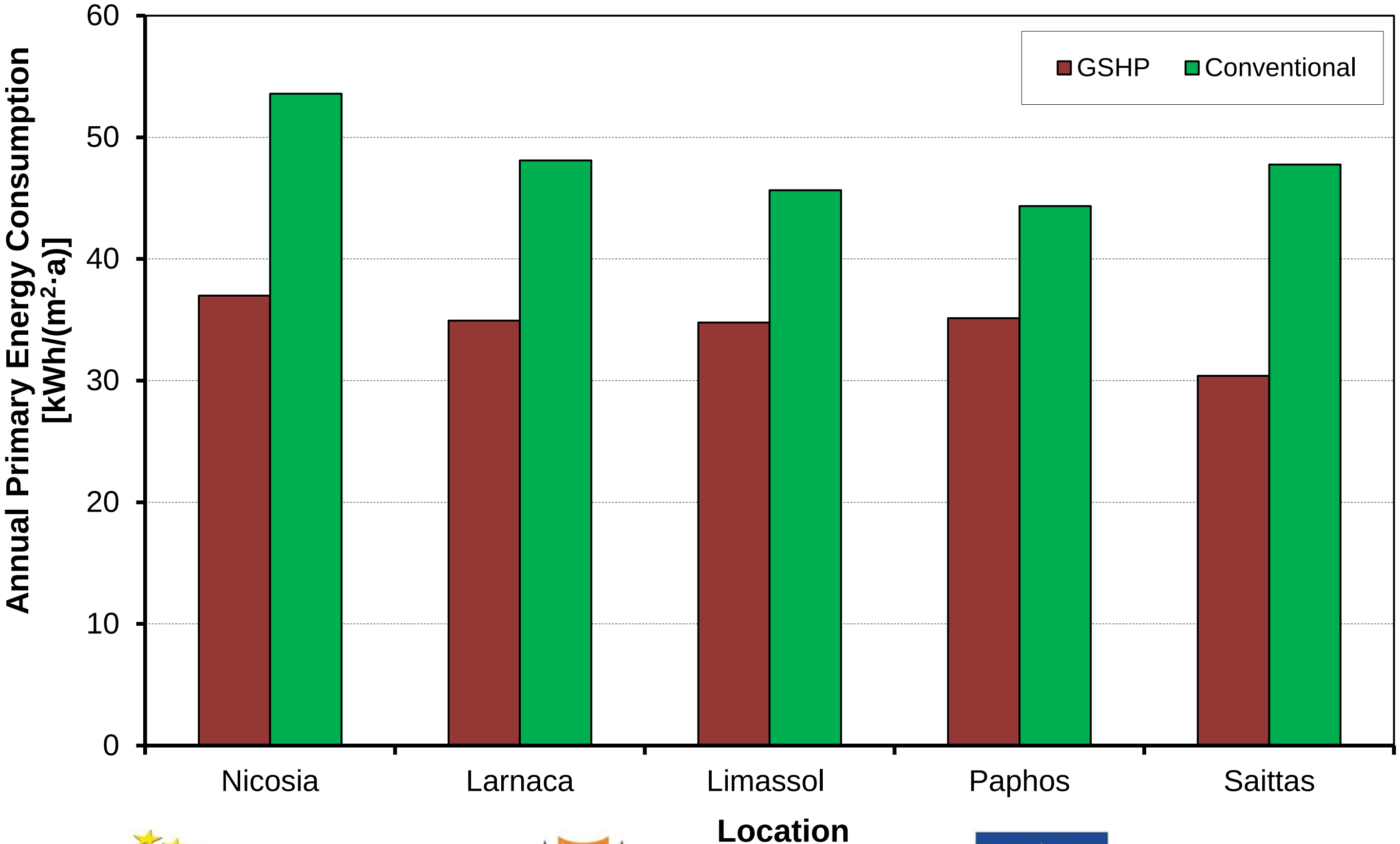
Conventional system:

- Oil-fired boiler and air-to-air-heat pump and
- LPG-fired boiler and air-to-air-heat pump and
  - Boiler efficiency: 0.92
- Heat pump:
  - Air-cooled chiller
  - Analysis on an hourly base using:
    - Energy demand of the building envelope,
    - Ambient temperature retrieved from Meteonorm database
    - EER provided by HP manufacturer

# Energy, Environmental and Economic Analysis – Office building

Office building – Energy evaluation

20.8% - 31.4% less

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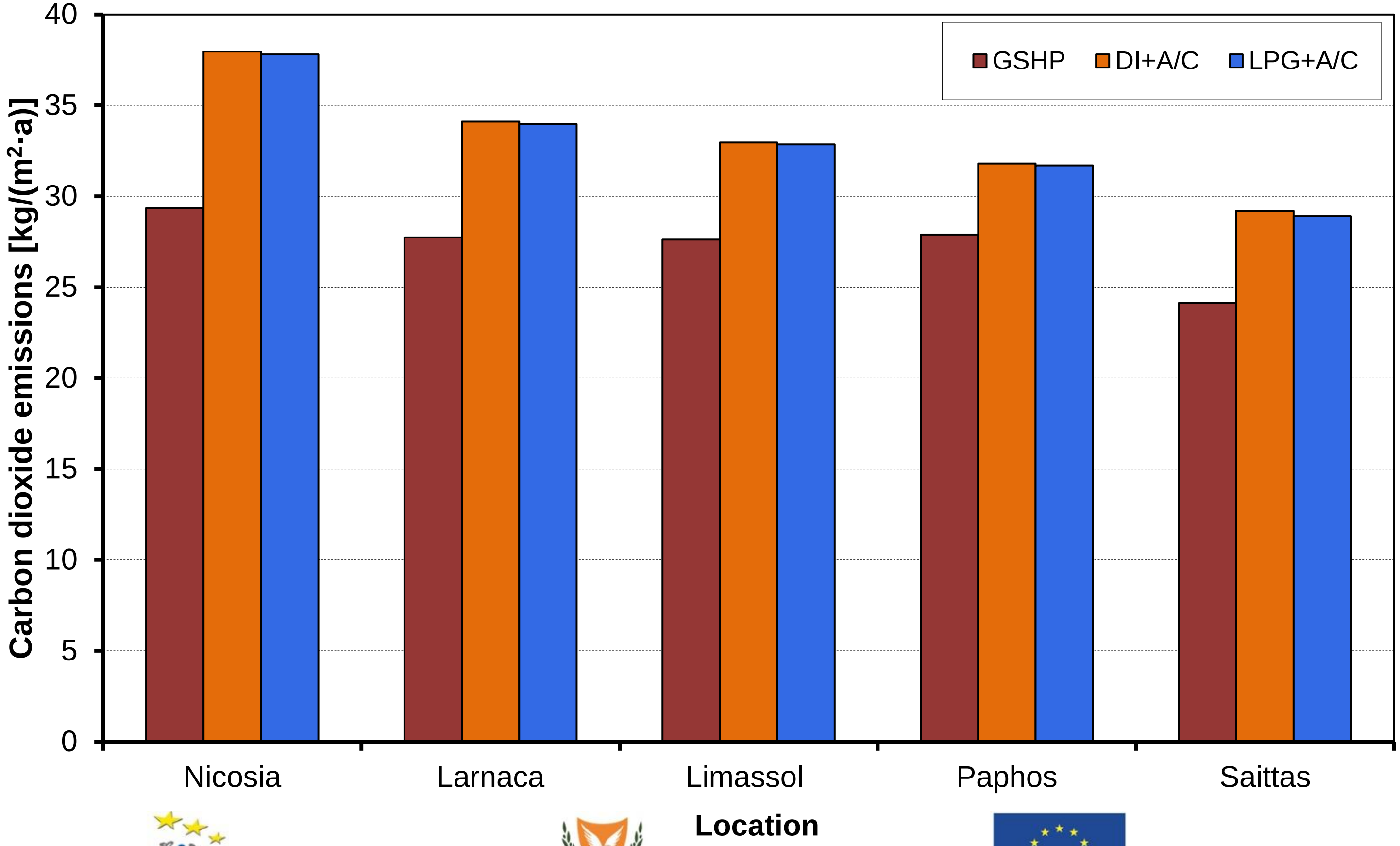
# Energy, Environmental and Economic Analysis – Office building

Office building – Environmental evaluation – Preliminary results

14.0% - 29.3% higher

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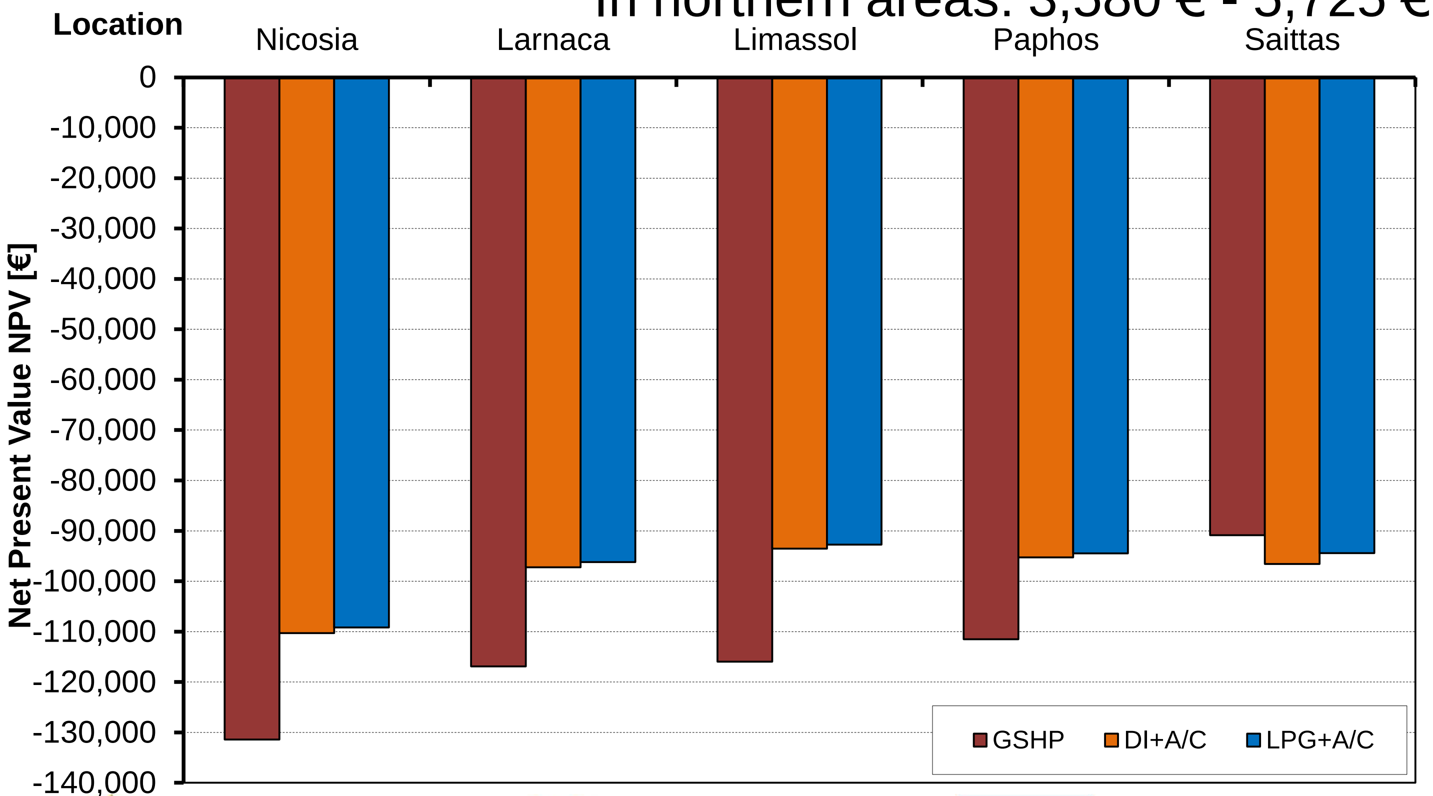
# Energy, Environmental and Economic Analysis – Office building

Office building – Economic evaluation – Preliminary results

In mainland and southern areas: 16,235 € - 23,230 € higher

In northern areas: 3,580 € - 5,725 € lower

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# Optimization of the energy behavior of the building envelope

Energy improvement interventions on the buildings' envelope:

- Enhancement of the opaque envelope
  - Thermal insulation
- Enhancement of the glazing envelope
  - Enhance the thermal characteristics of the openings' frame and glass
- Minimization of solar thermal gains
  - External shading
- Free cooling

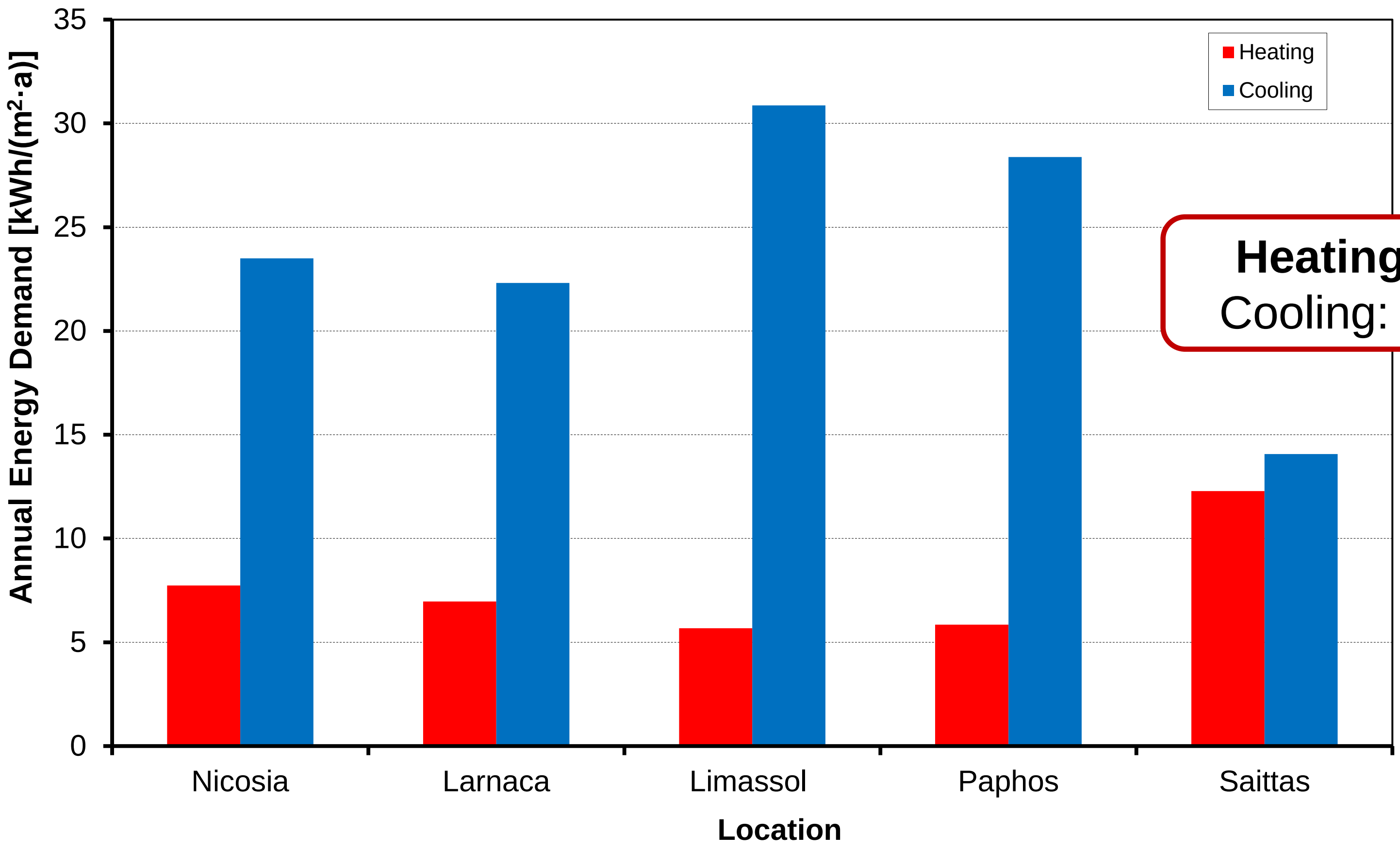
The optimum level of each intervention has been defined through a lifecycle cost analysis taking into consideration Regulation 244/2012/EC

# Characteristics of the low energy Office building (NZEB)

| Building Element | Location | | | | |
|---|---|---|---|---|---|
| | Nicosia | Larnaca | Limassol | Paphos | Saittas |
| Thermal transmittance of the vertical opaque envelope [W/(m$^2$·K)] | 0.49 | 0.49 | 0.49 | 0.49 | 0.42 |
| Thermal transmittance of pilotis [W/(m$^2$·K)] | 0.37 | 0.42 | 0.49 | 0.49 | 0.27 |
| Thermal transmittance of the roof [W/(m$^2$·K)] | 0.50 | 0.50 | 0.50 | 0.50 | 0.38 |
| Shading redaction factor | 0.58 | 0.58 | 0.58 | 0.58 | 0.58 |
| Thermal properties of the window elements [$U_f$ / $U_g$ / $g_w$] | 2.0 / 1.4 / 0.2 | 2.0 / 1.4 / 0.2 | 2.0 / 1.4 / 0.2 | 2.0 / 1.4 / 0.2 | 2.0 / 1.4 / 0.2 |
| Natural ventilation – Windows' opening percentage | 100% | 100% | 100% | 100% | 100% |

# Energy demand of the NZEB Office reference building

Office building, energy simulation results – NZEB



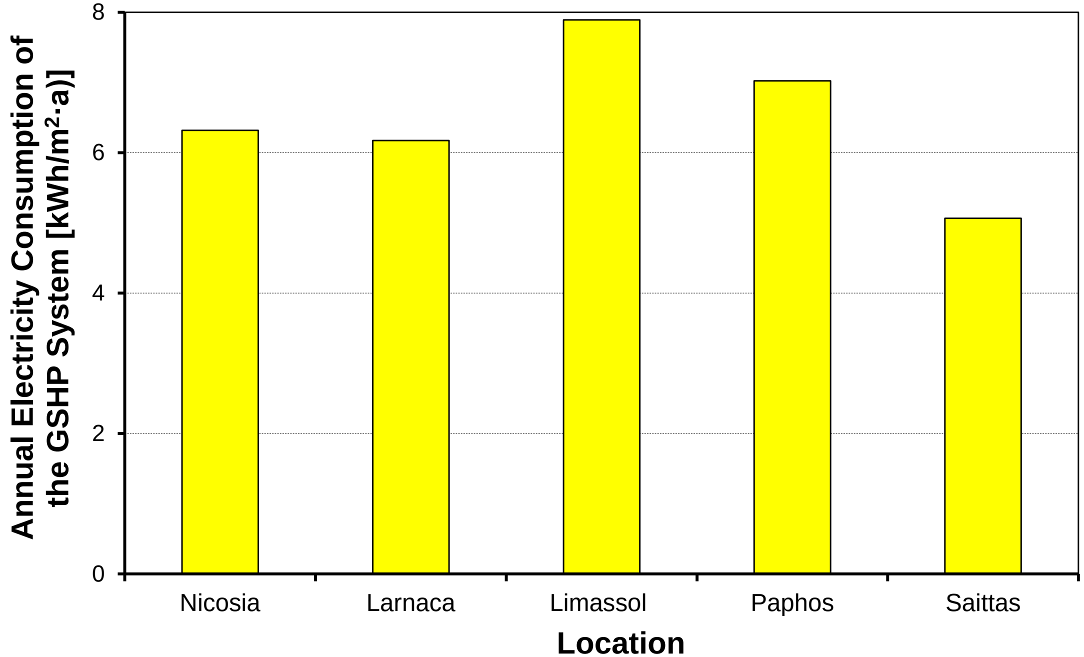

**Heating: -6% to +21%**
Cooling: -40% to -64.5%

# Design and simulation of the Ground Source Heat Pump system

Office building, design and simulation results – NZEB

Reduction: 2% - 31%

| Location | Boreholes x Length | Configuration |
|---|---|---|
| Nicosia | 12 x 103 m | Line: 1 x 12 |
| Larnaca | 9 x 116 m | Line: 1 x 9 |
| Limassol | 10 x 117 m | Line: 1 x 10 |
| Paphos | 10 x 114 m | Line: 1 x 10 |
| Saittas | 12 x 92 m | Rec: 3 x 4 |




Reduction: 39% - 55%

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# Energy, Environmental and Economic Analysis – Office building

Analysis of the **NZEB building**

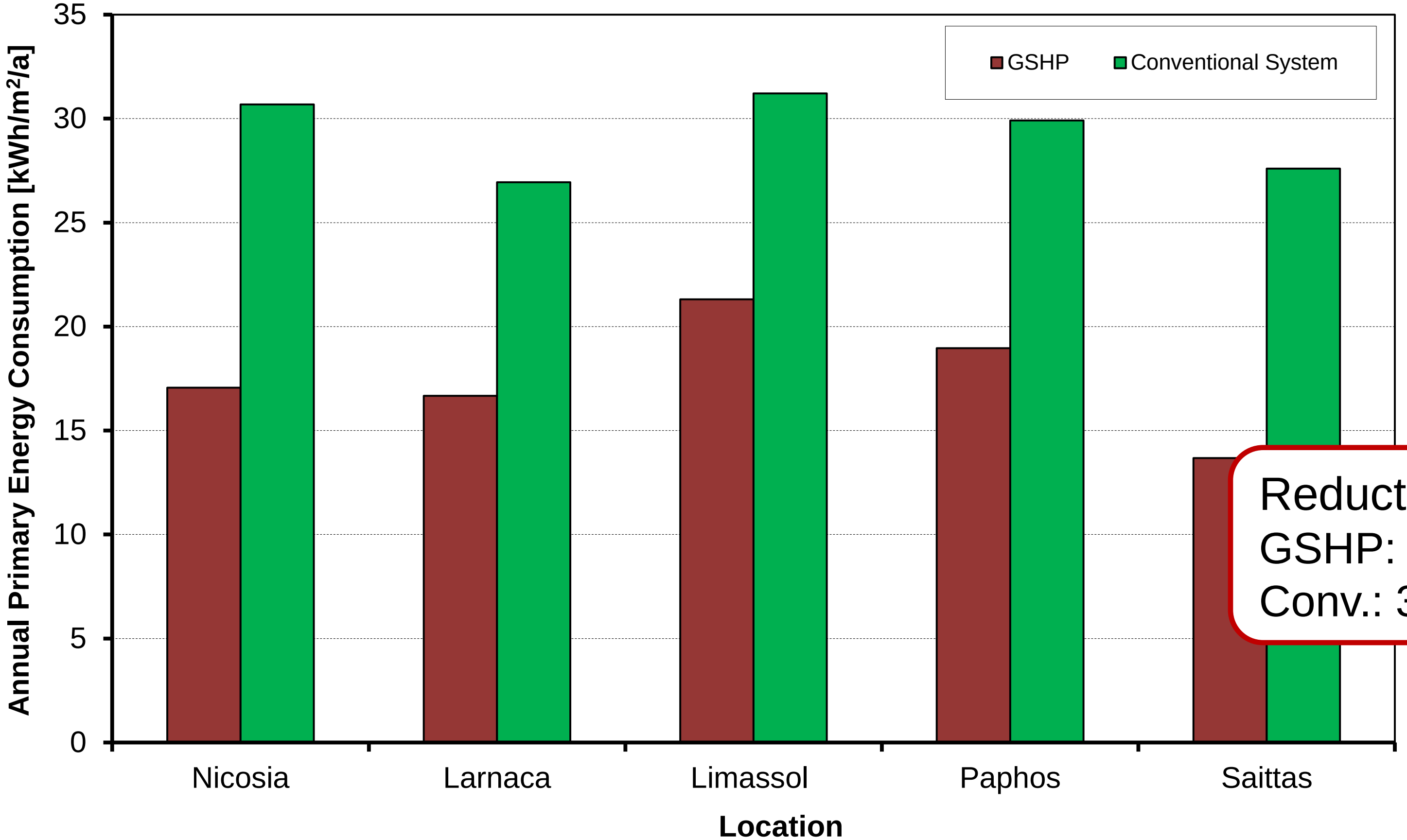
Conventional system:

- Oil-fired boiler and air-to-air-heat pump and
- LPG-fired boiler and air-to-air-heat pump and
  - Boiler efficiency: 0.92
- Heat pump:
  - Air cooled chiller
  - Analysis on an hourly base using:
    - Energy demand of the building envelope,
    - Ambient temperature retrieved from Meteonorm database
    - EER provided by HP manufacturer

# Energy, Environmental and Economic Analysis – Office building

## NZEB Office building – Energy evaluation

32% - 50.5% less




Reduction
GSHP: 46% - 55%
Conv.: 31.5% - 44%

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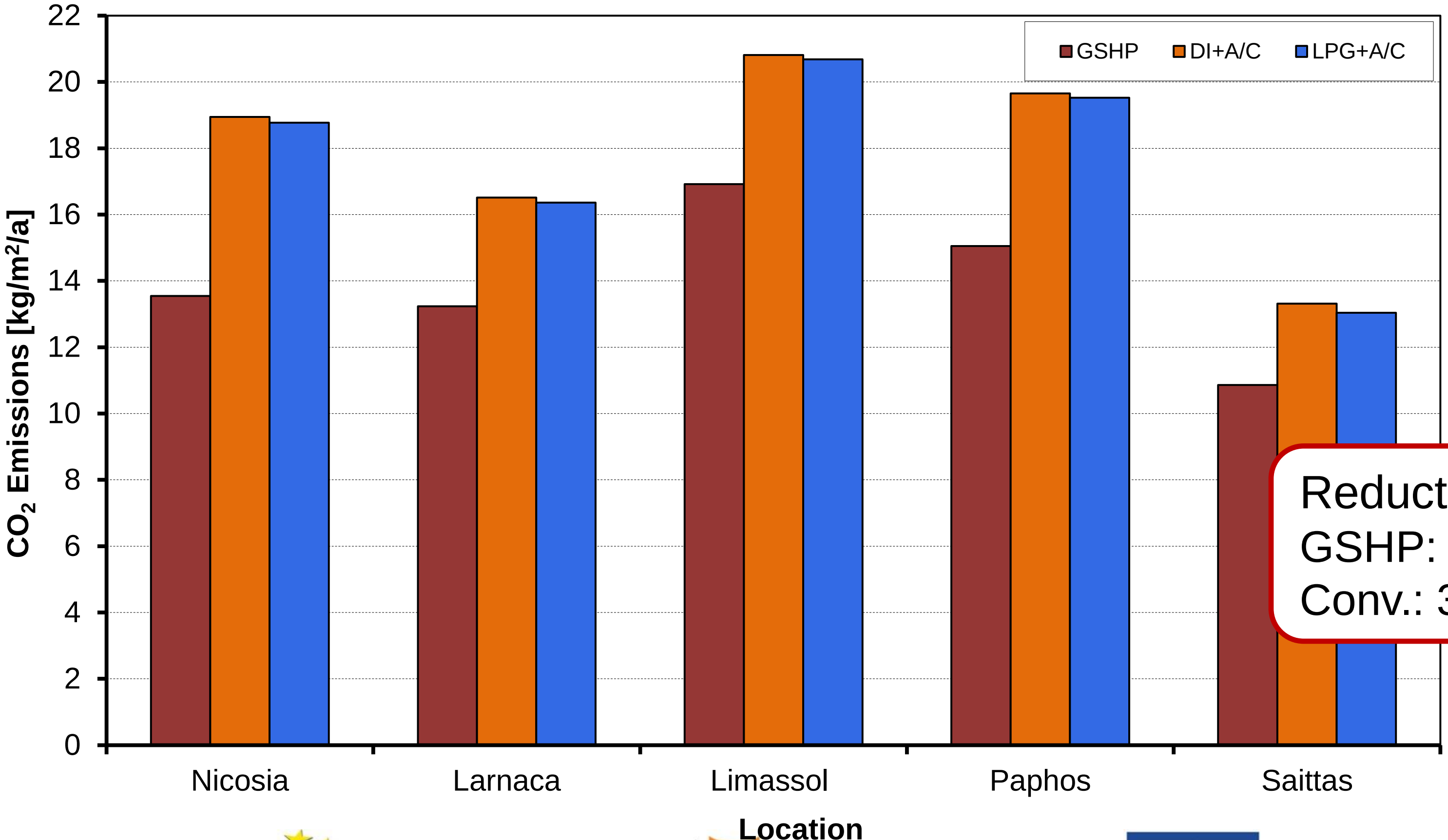
# Energy, Environmental and Economic Analysis – Office building

NZEB Office building – Environmental evaluation

20% - 40% higher




Reduction
GSHP: 39% - 55%
Conv.: 37% - 55%

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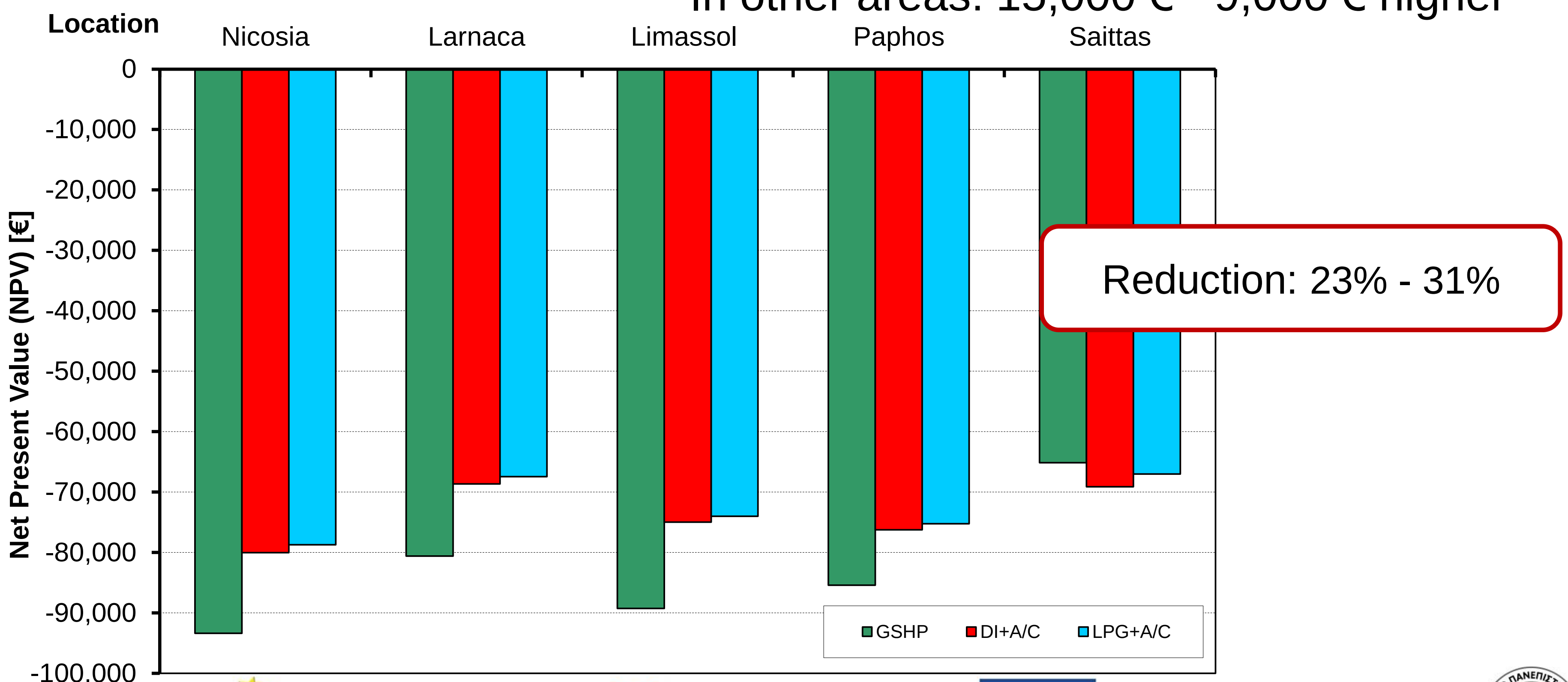
# Energy, Environmental and Economic Analysis – Office building

NZEB Office building – Economic evaluation

In Saittas: 4,000 € - 1,900 € lower

In other areas: 15,000 € - 9,000 € higher

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# Hybrid System: GSHP + Chiller

Office Building – Current practice – GHEx Design

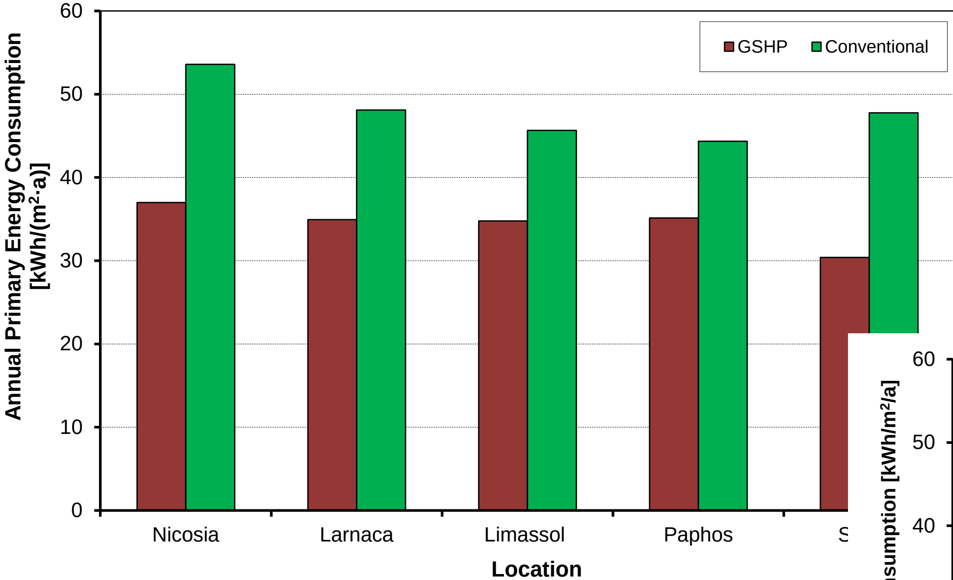
| Location | Boreholes x Length | Configuration |
|---|---|---|
| Nicosia | 12 x 120 m | Line: 1 X 12 |
| Larnaca | 12 x 126 m | Line: 1 X 12 |
| Limassol | 12 x 123 m | Line: 1 X 12 |
| Paphos | 10 x 118 m | Line: 1 X 10 |
| Saittas | 9 x 125 m | Line: 1 x 9 |

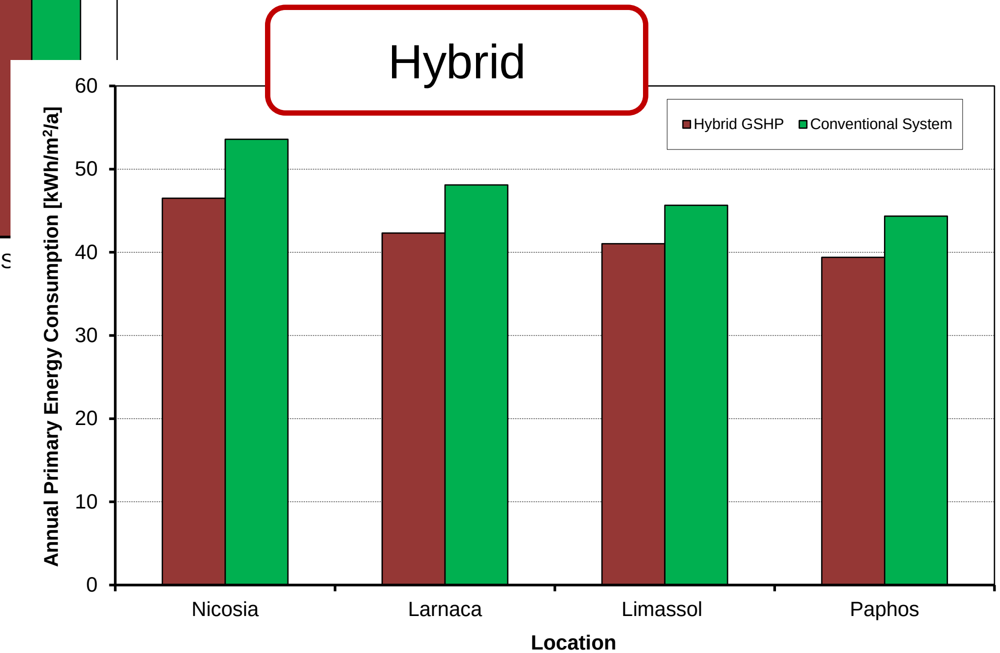
Hybrid

| Location | Boreholes x Length | Configuration |
|---|---|---|
| Nicosia | 7 x 70 m | Rec.: 2 x 3 |
| Larnaca | 6 x 78.5 m | Rec.: 2 x 3 |
| Limassol | 6 x 76 m | Rec.: 2 x 3 |
| Paphos | 6 x 77 m | L.: 3 x 5 |
| Saittas | - | - |

# Hybrid System: GSHP + Chiller

## Office Building – Current practice – Energy Evaluation

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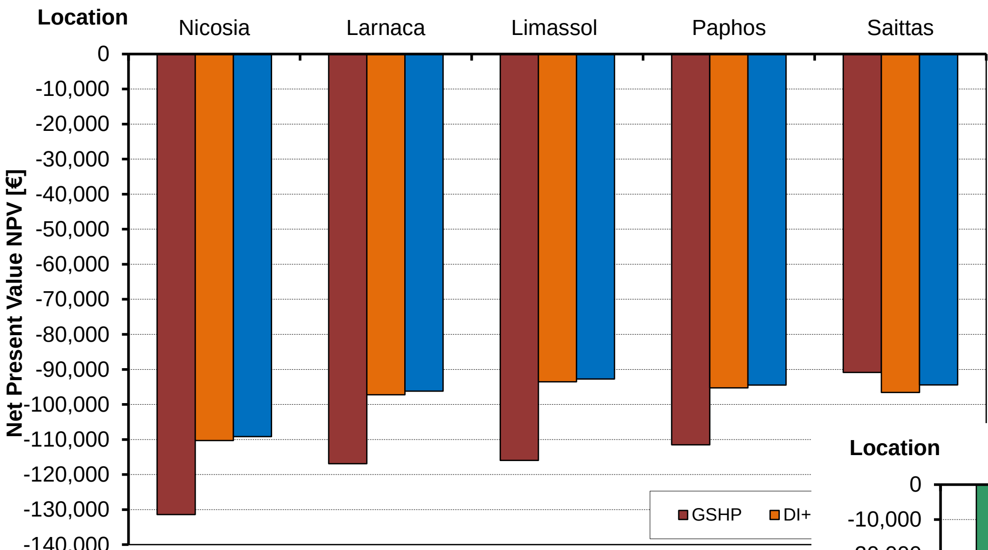
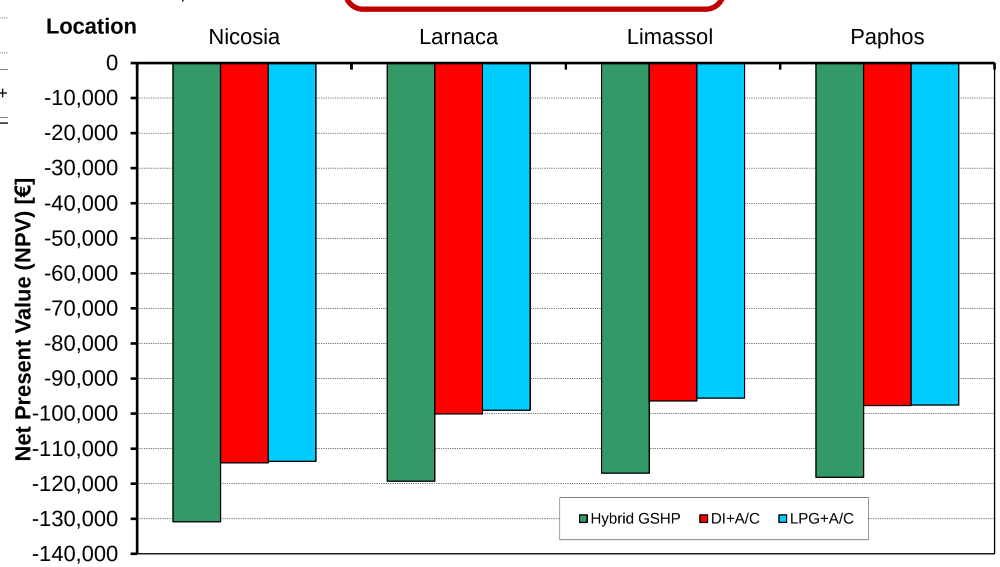
# Hybrid System: GSHP + Chiller

## Office Building – Current practice – Economic Evaluation




Hybrid

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# Hybrid System: GSHP + Chiller

Office Building – NZEB – GHEx Design

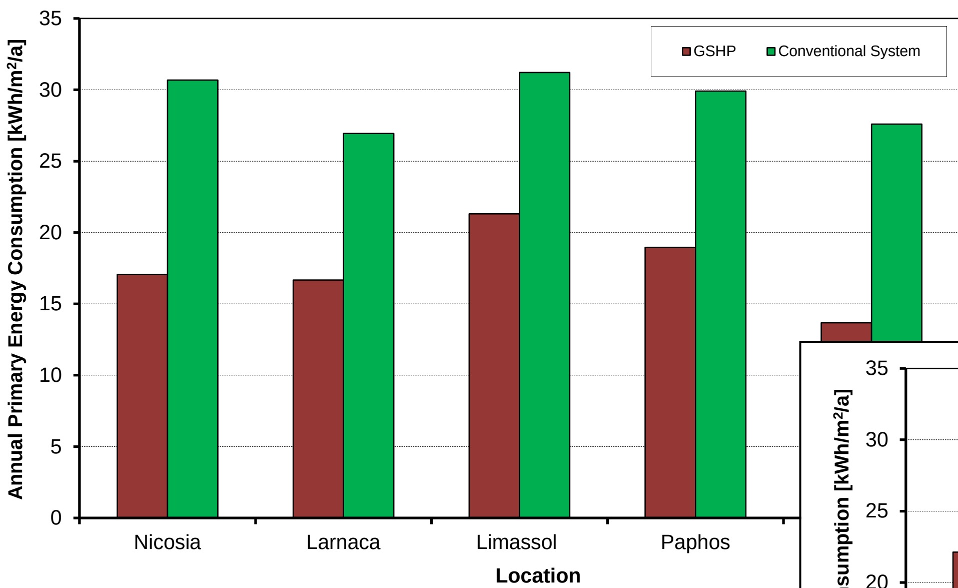
| Location | Boreholes x Length | Configuration |
|---|---|---|
| Nicosia | 12 x 103 m | Line: 1 x 12 |
| Larnaca | 9 x 116 m | Line: 1 x 9 |
| Limassol | 10 x 117 m | Line: 1 x 10 |
| Paphos | 10 x 114 m | Line: 1 x 10 |
| Saittas | 12 x 92 m | Rec: 3 x 4 |

Hybrid

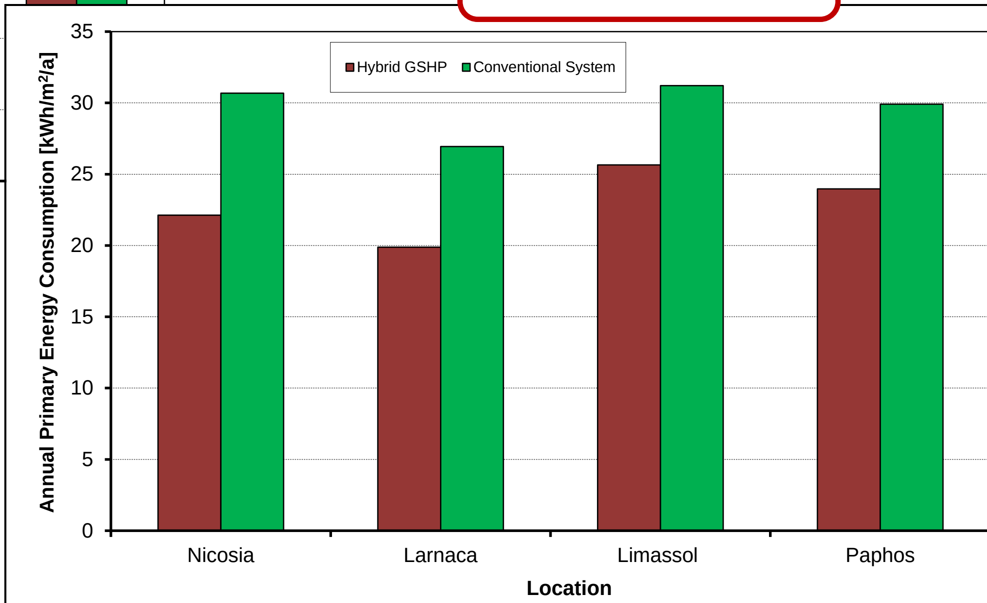
| Location | Boreholes x Length | Configuration |
|---|---|---|
| Nicosia | 8 x 70 m | Line: 1 x 8 |
| Larnaca | 7 x 78 m | Line: 1 x 7 |
| Limassol | 7 x 70 m | Line: 1 x 7 |
| Paphos | 8 x 73 m | Line: 1 x 8 |
| Saittas | - | - |

# Hybrid System: GSHP + Chiller

## Office Building – NZEB – Energy Evaluation

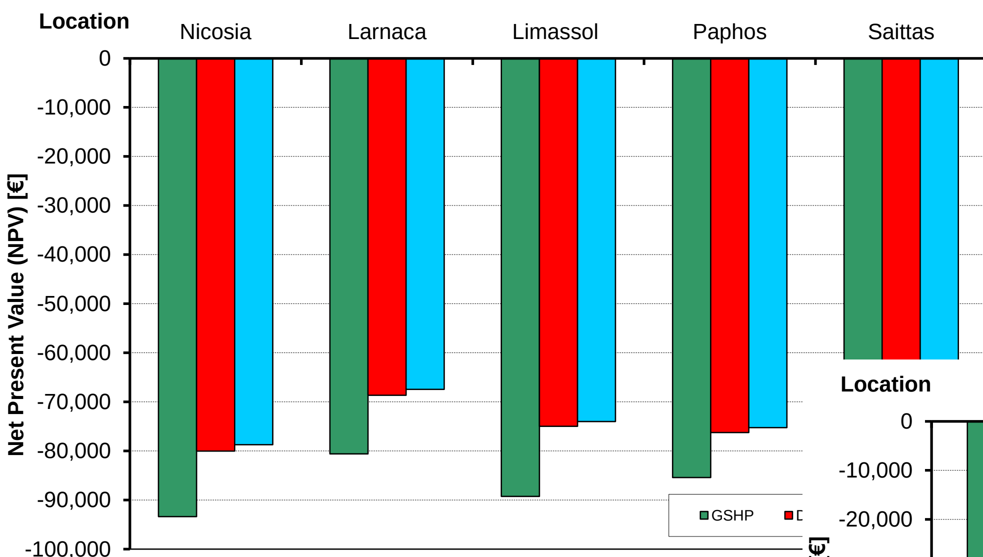



Hybrid

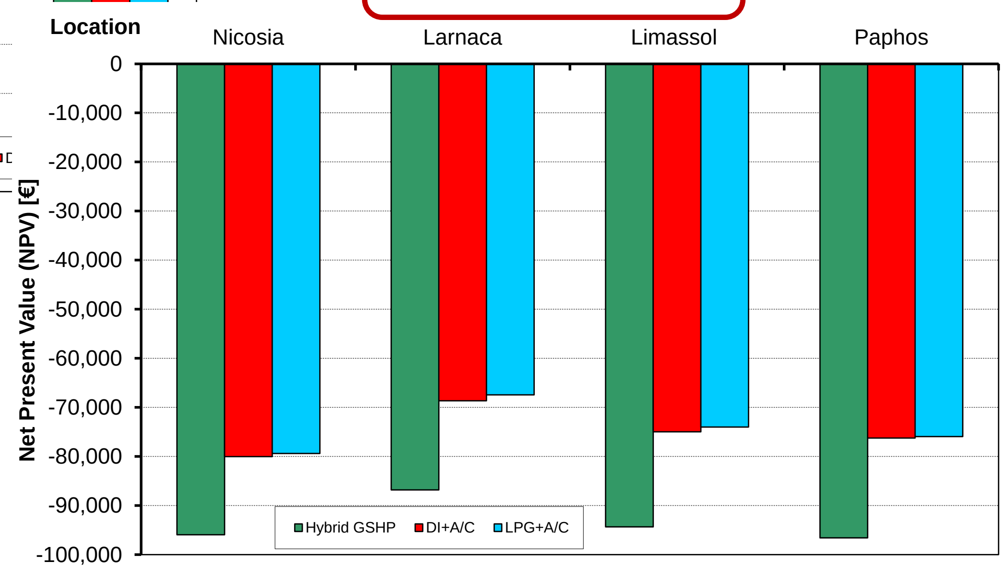


# Hybrid System: GSHP + Chiller

## Office Building – NZEB – Energy Evaluation




Hybrid

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Thank you very much for your attention!!

Discussion ….