Micro-Trigeneration in Energy Efficient Residential Buildings in Southern Europe

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Scope of research

- Extend previous work done on micro-cogeneration in residential buildings to include a cooling aspect (micro-trigeneration)

- Investigate how a residential micro-trigeneration system would perform under varying conditions of demand and supply caused by changing external operating conditions related to energy-efficiency improvements in residential buildings and the grid network

- The research also adds to existing studies on trigeneration by:

  (i) *Including new aspects in relation to modelling high resolution residential electrical demand profiles and the effect energy-efficiency improvement measures could have on these profiles and eventually on micro-trigeneration system performance;* and

  (ii) *Presenting the development of a detailed yet easy-to-calibrate absorption chiller model capable of capturing the dynamic behaviour of such a component without the complexities typically involved in such a type of modelling*

Importance of Research

- ✓ Improving energy-efficiency and reducing emission is a very important target for most countries and institutions

- ✓ Recognised difficulty in achieving the targets set, especially on the domestic sector level (~25% of the total energy consumption in the EU)

- ✓ A more concrete action is needed – Residential micro-trigeneration, a possible way forward to efficiently provide heating, cooling and power in southern European countries

- ✓ In general the performance of micro-trigeneration (~15 kW_{el}) in residential single-family or small multi-family household buildings has only been superficially researched
    - ➢ *Especially true when considering the effect of varying operating conditions on the energetic, environmental and economic performance of micro-trigeneration in residential buildings*

Importance of Research

- ✓ **Provides a detailed analysis on the effect other energy-efficiency improvements measures will have on the performance of a residential micro-trigeneration system**
  - ➢ ***Useful in policy development***

- ✓ **Assess the contribution (and feasibility) of micro-trigeneration in (current and future) Maltese (but also applies to other southern European countries) residential buildings**

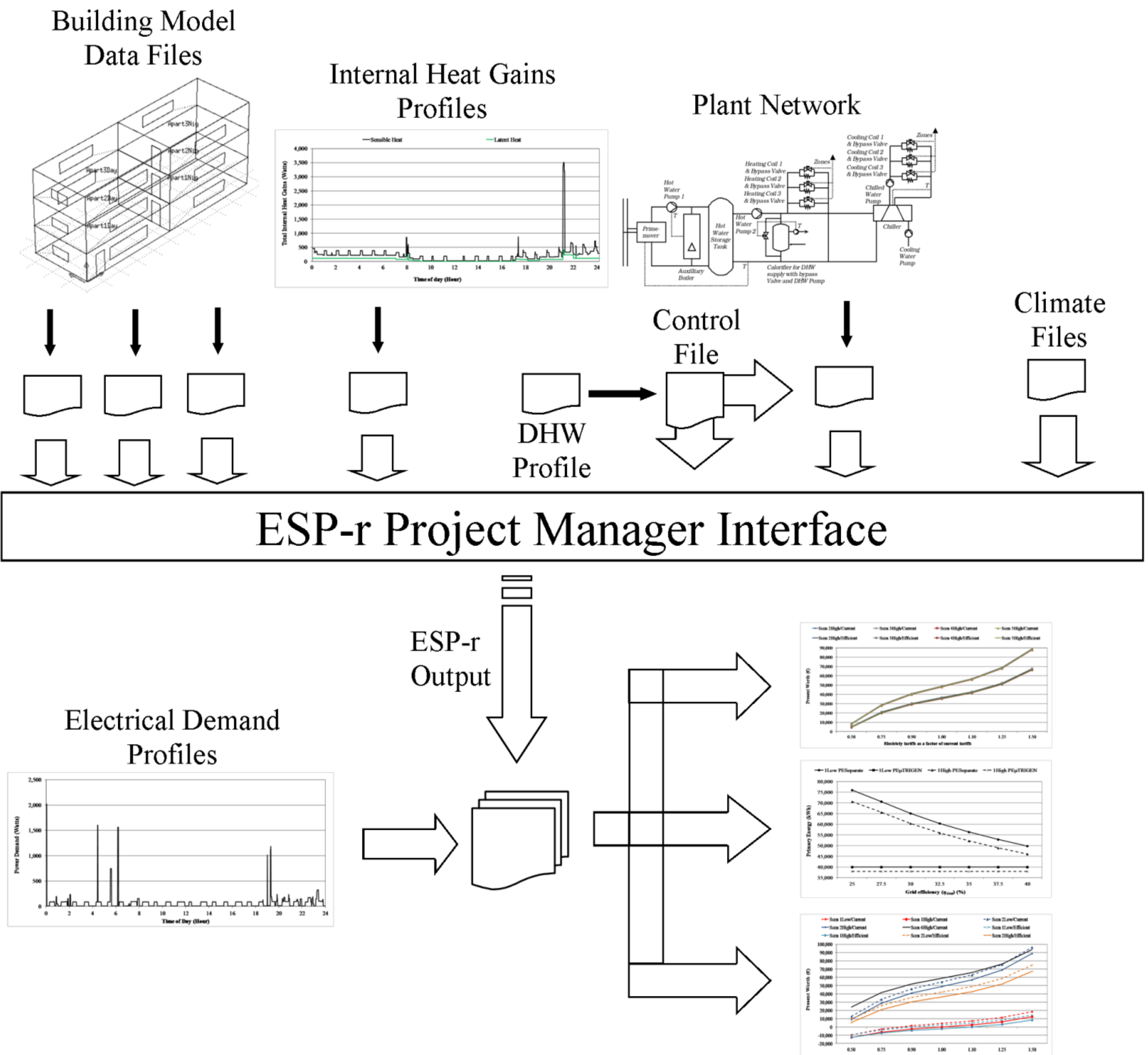
Methodology

- The research makes use of the whole building simulation tool ESP-r to simulate the performance of a grid connected micro-trigeneration system under a number of varying external operating conditions
- System is modelled to represent a micro-trigeneration system supplying both the electrical and the HVAC demand of a (3 and 6 household) multi-family residential building in the Mediterranean island of Malta
- By changing a specific condition each time (*e.g.* the building fabric, building size, electrical efficiency, *etc.*), various scenarios were created such that the effect caused on the performance of the micro-trigeneration system by that external parameter could be analysed
- The creation of different scenarios involved either:
  - *Directly changing the input parameters of the ESP-r model; or*
  - *Post-processing of the data obtained from the simulations performed*

Operating Conditions Investigated

Operating Condition	Possible effect on micro-trigeneration system
Improvement in building fabric	Changes the thermal demand
Building size and number of occupants	Changes the thermal demand
Addition of a chilled water storage tank	Changes operating mode
Improvement in household appliances' electrical efficiency	Changes the electrical demand
Addition of a solar water heating system in tandem with micro-trigeneration system	Changes the thermal demand
Sensitivity to grid network improvements	Changes the comparison with separate generation
Sensitivity to fuel prices	Changes the system's running costs
Sensitivity to electricity tariffs	Changes the comparison with separate generation

Use of ESP-r

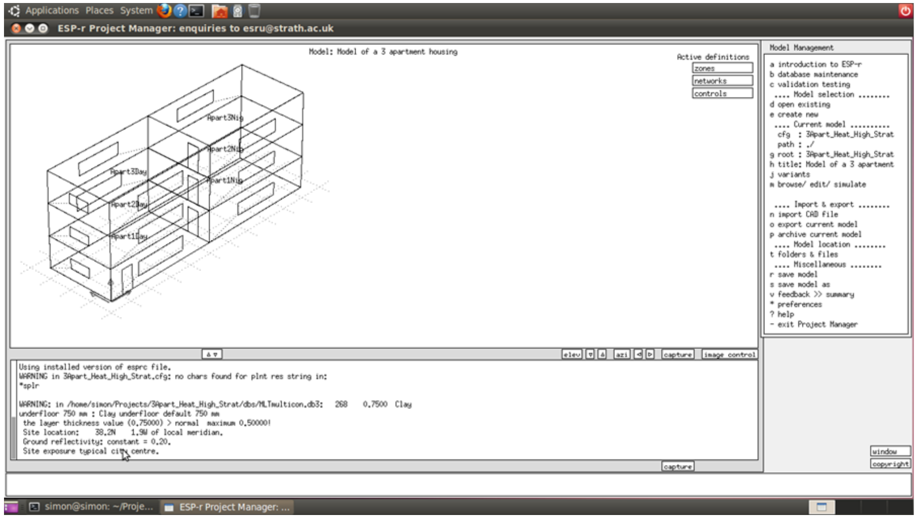


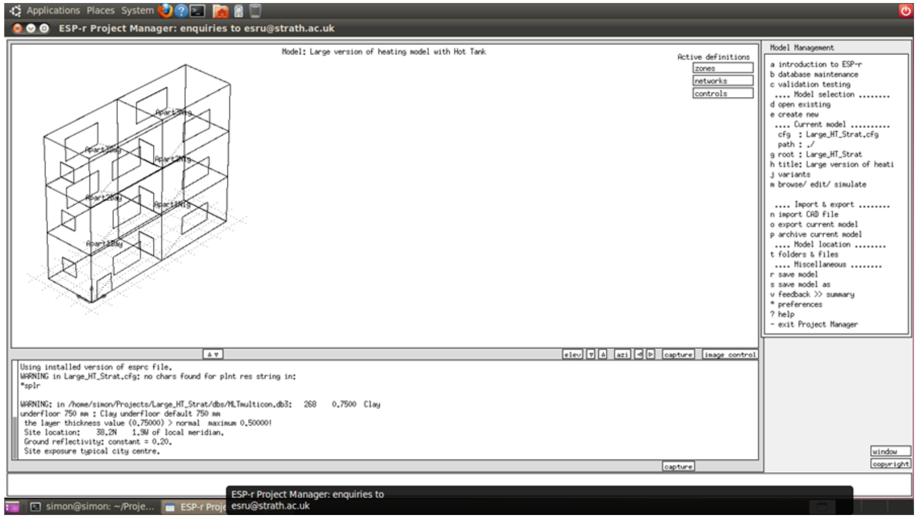
The building simulation tool ESP-r acts as the interface which permits the modelling of the supply side (the micro-trigeneration system made up of multiple components) and the demand side (the user specified internal heat gains and building characteristics *etc.*)

Scenarios Modelled

$Scenario_{Building\ fabric/Electrical\ efficiency}$	Type of building fabric	Household appliance electrical efficiency	Building type (Occupancy)	Type of plant configuration	Scope of scenario
$1_{Low/Current\ efficiency}$	**Poorly-insulated fabric scenario**	Current efficiency	3 Household building (9 Persons)	Basic plant configuration	**Investigate the effect of improving the building fabric and the electrical efficiency of household electrical appliances on system performance**
$1_{Low/High\ efficiency}$		High efficiency			
$1_{High/Current\ efficiency}$	**Highly-insulated fabric scenario**	Current efficiency			
$1_{High/High\ efficiency}$		High efficiency			
$2_{Low/Current\ efficiency}$	**Poorly-insulated fabric scenario**	Current efficiency	6 Household building (18 Persons)	Basic plant configuration	**By comparing with Scenario 1, investigate the effect of building size and occupancy on system overall performance**
$2_{Low/High\ efficiency}$		High efficiency			
$2_{High/Current\ efficiency}$	**Highly-insulated fabric scenario**	Current efficiency			
$2_{High/High\ efficiency}$		High efficiency			
$3_{High/Current\ efficiency}$	**Highly-insulated fabric scenario**	Current efficiency	6 Household building (18 Persons)	Basic plant configuration with additional 0.3m^3 chilled water tank	**Investigate the effect of including an additional chilled water tank in the system configuration**
$3_{High/High\ efficiency}$		High efficiency			
$4_{High/Current\ efficiency}$	**Highly-insulated fabric scenario**	Current efficiency	6 Household building (18 Persons)	Basic plant configuration with additional 2.5m^2 flat plate SWH	**Investigate the effect of including a SWH in the system configuration**
$4_{High/High\ efficiency}$		High efficiency			
$5_{High/Current\ efficiency}$	**Highly-insulated fabric scenario**	Current efficiency	6 Household building (18 Persons)	Basic plant configuration; All cogenerated electricity was exported to the grid	**Investigate the financial sensitivity of the system to exporting all the electricity**
$5_{High/High\ efficiency}$		High efficiency			

Buildings Modelled





<u>3 Households building</u>
modelled to represent 3 households, one household for each floor

Each floor 20m*12m*2.7m

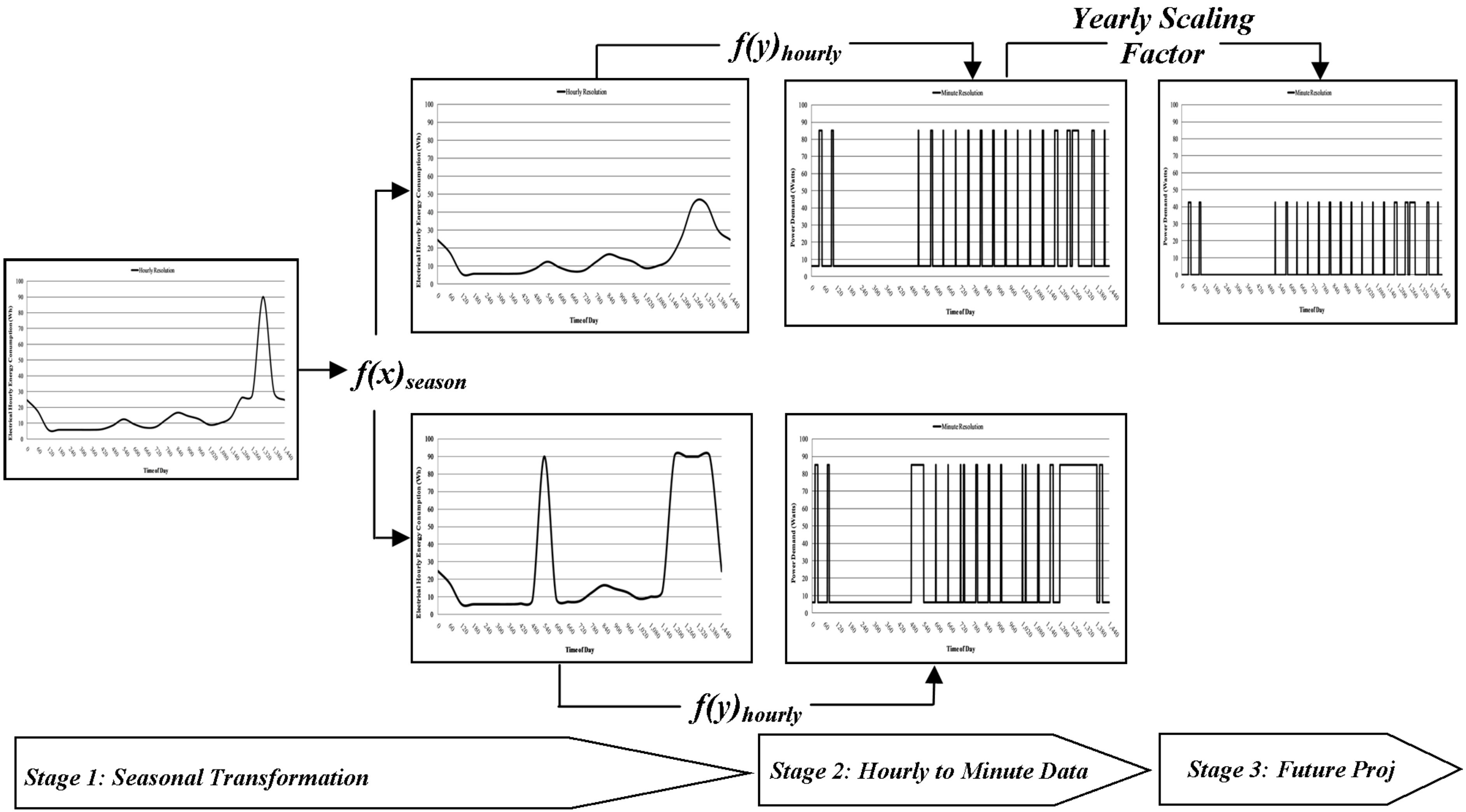
<u>6 Households building</u>
modelled to represent 6 households, two households for each floor. Includes added thermal mass

Each floor 20m*12m*5.4m

Building Fabric

Item	Poorly-insulated building fabric scenario	Highly-insulated building fabric scenario
South façade exposed external walls	230mm soft limestone block / 10 mm cavity / 150mm concrete block / 12.5mm gypsum board **Total U-Value - 1.194 W/m²K**	230mm soft limestone block / 50mm expanded polystyrene / 150mm concrete block / 12.5mm gypsum board **Total U-Value - 0.428 W/m²K**
Other exposed external walls	230mm concrete block / 12.5mm gypsum board **Total U-Value - 1.889 W/m²K**	230mm soft limestone block / 50mm expanded polystyrene / 150mm concrete block / 12.5mm gypsum board **Total U-Value - 0.428 W/m²K**
Non-exposed external walls	230mm concrete block / 12.5mm gypsum board **Total U-Value - 1.889 W/m²K**	230mm concrete block / 10mm expanded polystyrene board / 12.5mm gypsum board **Total U-Value - 1.159 W/m²K**
Internal walls	150mm concrete block finished on both sides with 12.5mm gypsum board **Total U-Value - 1.907 W/m²K**	
Roof	4mm dark coloured roof felt / 75mm lean concrete mix / 100mm layer of crushed limestone / 150mm 2% steel reinforced concrete / 12.5mm ceiling gypsum board **Total U-Value - 1.390 W/m²K**	12mm white coloured roof felt having solar absorption 0.5 / 75mm lean concrete mix / 100mm layer of crushed limestone / 180mm roof insulation board / 150mm 2% steel reinforced concrete / 12.5mm ceiling gypsum board **Total U-Value - 0.588 W/m²K**
Ceiling	6mm tile / 50mm lean concrete mix / 50mm layer of crushed limestone / 150mm 2% steel reinforced concrete covered / 12.5mm ceiling gypsum board **Total U-Value - 1.722 W/m²K**	6mm tile / 50mm lean concrete mix / 50mm layer of crushed limestone / 50mm roof insulation board / 150mm 2% steel reinforced concrete / 12.5mm ceiling gypsum board **Total U-Value - 1.185 W/m²K**
Glazing	6mm single glazing **Total U-Value - 3.733 W/m²K**	Air filled 6mm double glazing with 12mm gap **Total U-Value - 2.265 W/m²K**

High resolution electrical demand modelling



High resolution electrical demand modelling (2)

Stage 1 - Introducing monthly variation

Expand on limited amount of data to introduce seasonal variation

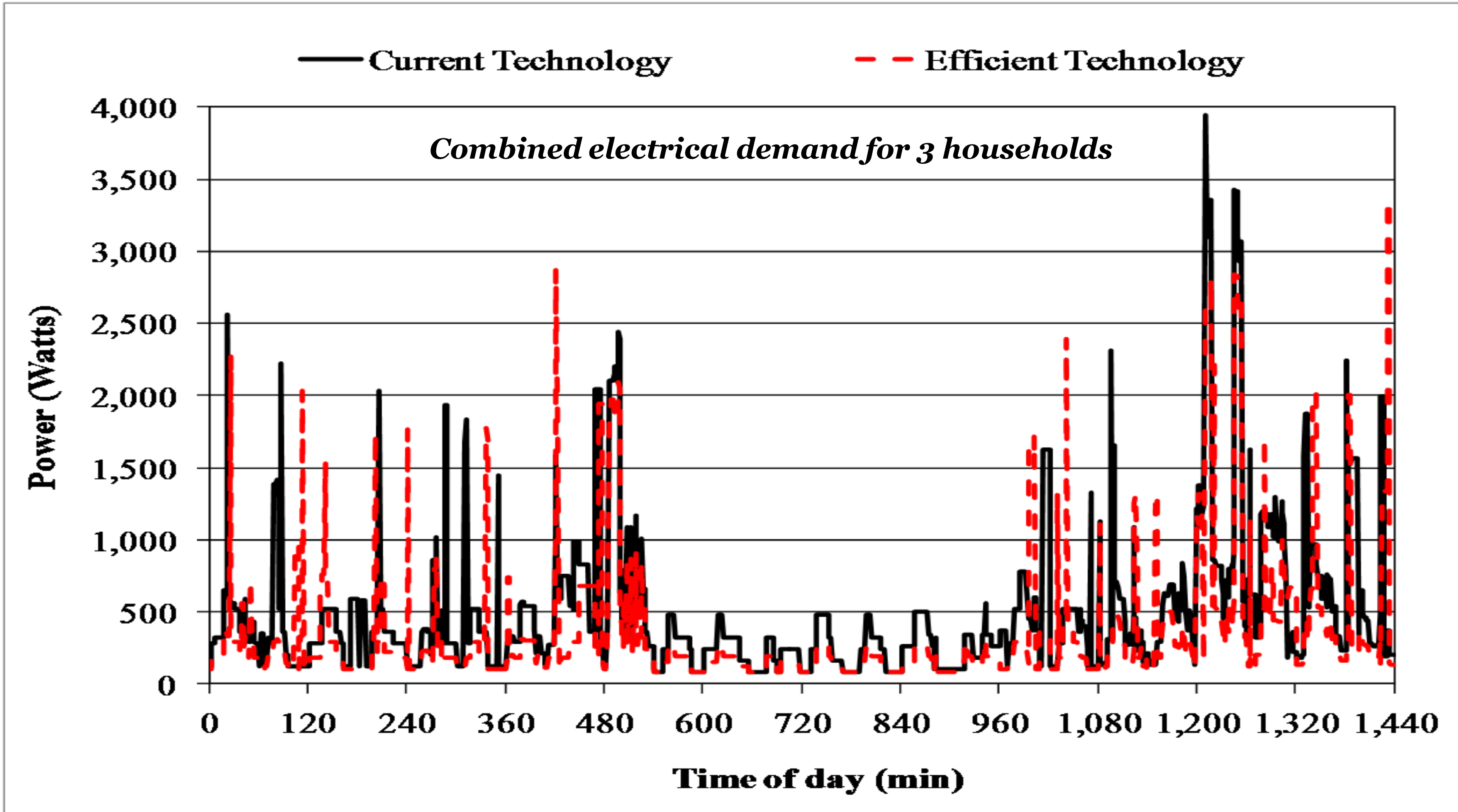
Stage 2 - Converting to 1-minute time resolution

Takes on from the work done in Stage 1 to produce 1-minute time resolution load profiles for each hour of each individual appliance. The modelled profile is based on whether an appliance follows a simple square “ON”/”OFF” pulse pattern, varying between zero power during its “OFF” state, and a steady-state operating power during its “ON” state, *or* modelled using a known energy utilisation pattern

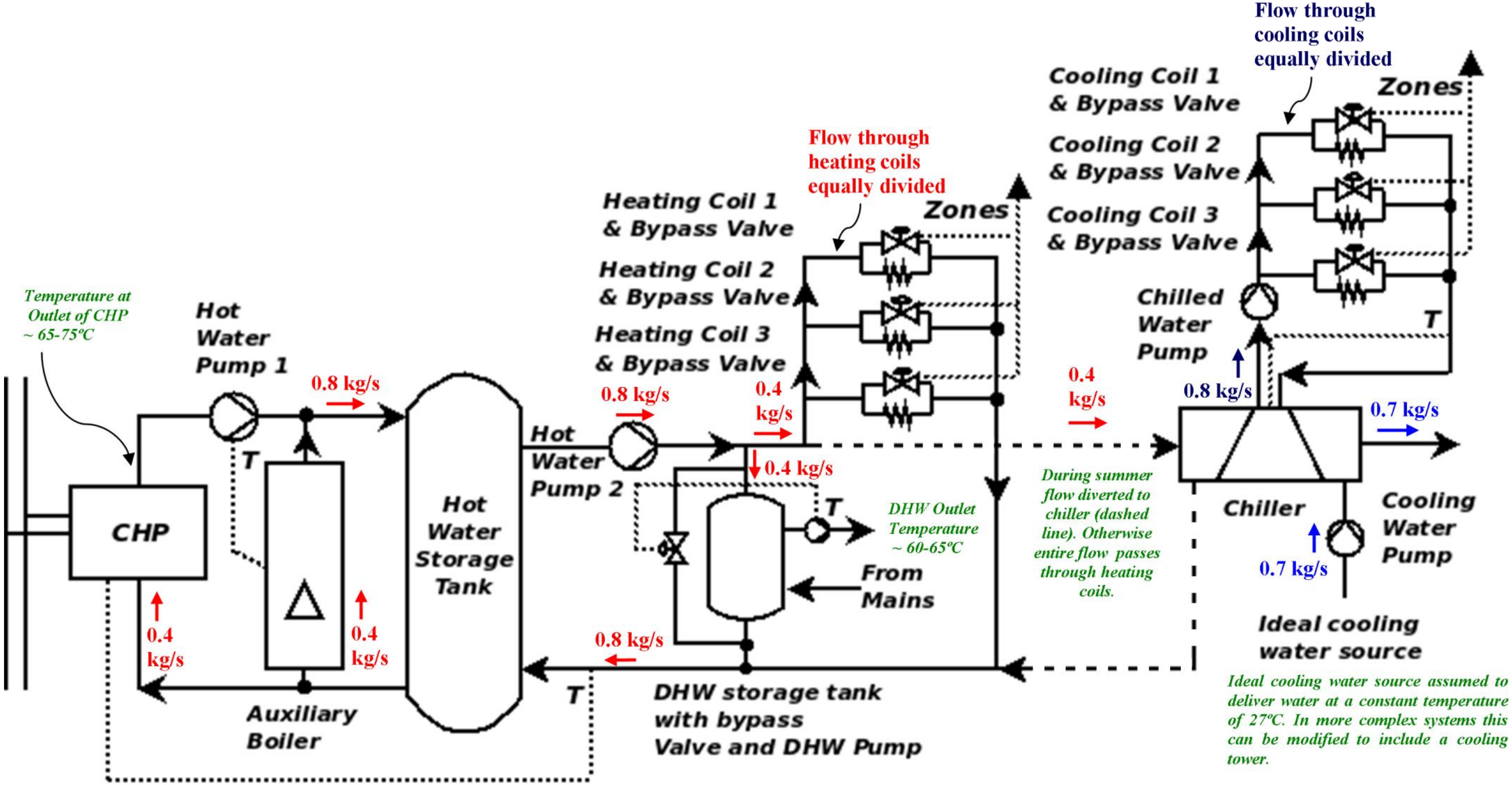
Stage 3 - Accounting for improvements in energy efficiency

Uses scaling factors to project the present electrical power demand of a number of appliances to represent improvements in energy efficiency for each individual appliance

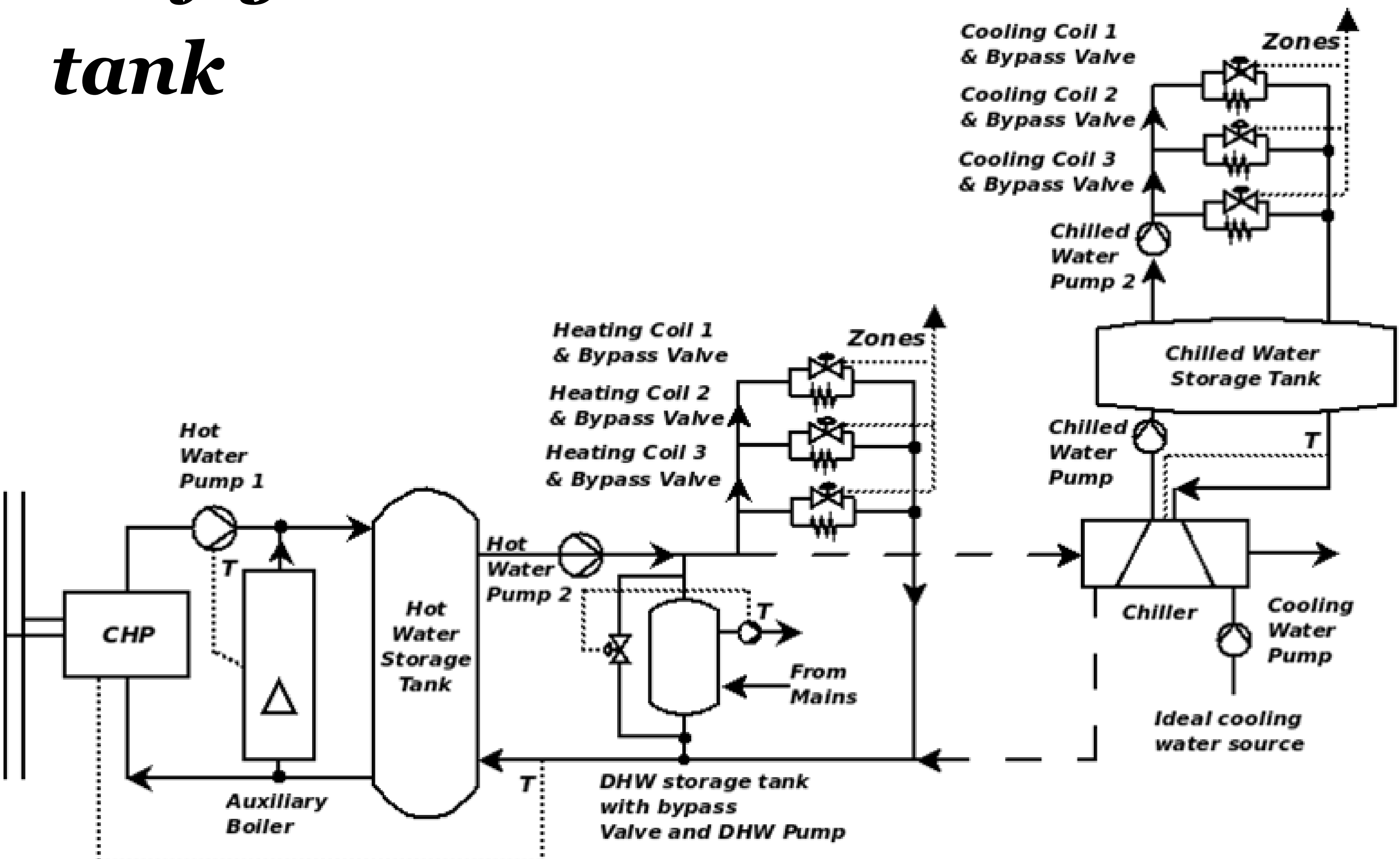
High resolution electrical demand modelling (3)



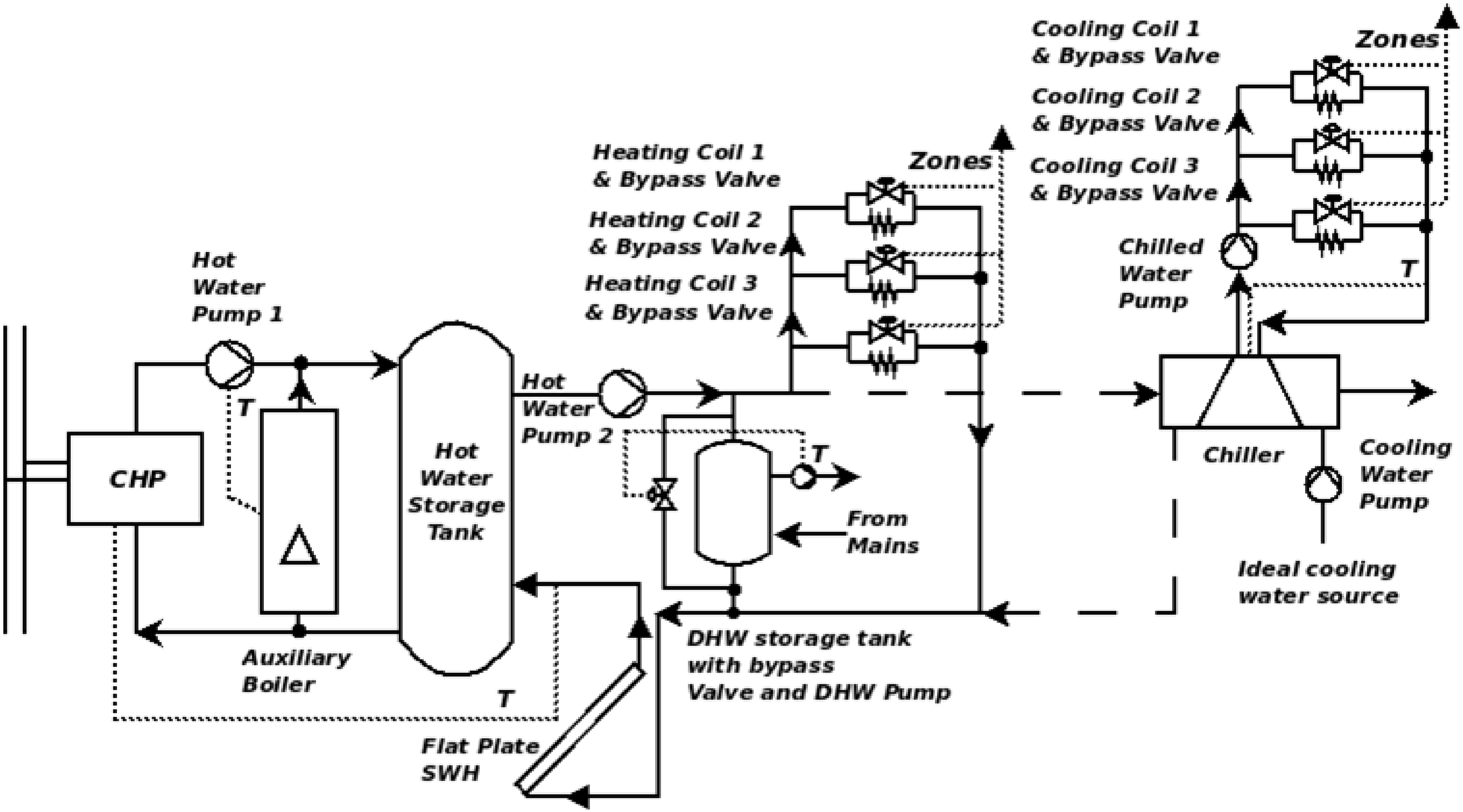
Base case plant configuration



Base case plant configuration with chilled water tank



Base case plant configuration with SWH



Simulations

- Each individual scenario was simulated for a whole year - Sub-divided into three seasons, the heating season (mid-December to mid-March), the cooling season (June to September) and the remaining shoulder months

- All simulations performed were run at a high temporal resolution of 1 minute to ensure that the simulations were modelled with enough temporal precision to pick the highly varying nature of residential energy demands

- The effect individual parameters had on the system's performance was gauged using either:
  - A ***deterministic method*** approach, where individual cases were assessed with respect to selected parameters and then compared to other scenarios (*incl*. base case scenarios)

  - A ***sensitivity analysis*** approach, where the effect of a specific parameter on the system's performance was gauged through the gradual change of the parameter in question

Simulations (2)

For the ***Sensitivity Analysis*** part, each scenario modelled was post-processed to examine the sensitivity of the results obtained for that scenario vis-à-vis:

- ***Grid network improvements:*** In assessing the energetic and environmental performance of the system in comparison with separate generation, the grid efficiency and the grid emissions factor values used in the calculation of the energy required and associated emissions emitted to produce the same energy products in separate generation, were varied to represent different grid network improvements scenarios

- ***Gas prices and electricity tariffs:*** In assessing the financial performance of a system, the electricity tariff and the gas price used in the calculation of the investment criteria of the different scenarios, were varied to represent different financial scenarios

Performance Assessment

- **Energetic Assessment**
- **Environmental Assessment**
- **Economic Assessment**

Energetic Performance Assessment (1)

Measured Metrics

Supplied thermal energy

- ✓ Space Heating (E_{SH})
- ✓ Space Cooling (E_{SC})
- ✓ Hot Water Demand (E_{DHW})

Electrical performance of the system

- ✓ Net electrical imports ($E_{Net\ Import}$)
- ✓ Net demand satisfied by µTrigen System ($E_{Net\ Demand\ \mu TRIGEN}$)
- ✓ Net electrical exports ($E_{Net\ Export}$)

System's performance

- ✓ CHP and auxiliary boiler fuel consumption
- ✓ Primary Energy used ($PE_{\mu Trigen}$)
- ✓ System Efficiency ($\eta_{\mu TRIGEN}$)

Comparison with separate generation

- ✓ Equivalent energy required in separate generation ($PE_{SEPERATE}$)
- ✓ System's Primary Energy Savings (PES)

Energetic Performance Assessment (2)

Equations

$$PE_{\mu TRIGEN} = \left(\sum_{n=1}^{n} \left(\left(\dot{m}_{FUEL(CHP)} \right)_n + \left(\dot{m}_{FUEL(Aux)} \right)_n \right) * C_{LPG} \right) * 16.667$$

$$\eta_{\mu TRIGEN} = \frac{\left(E_{SH} + E_{SC} + E_{DHW} + E_{Net\ Demand\ \mu TRIGEN} + E_{Net\ Export} \right) * 100}{\left(PE_{\mu TRIGEN} \right)}$$

$$PE_{SEPERATE} = \frac{\left(\frac{E_{DHW}}{\eta_{Water}} + E_{Net\ Demand\ \mu TRIGEN} + E_{Net\ Export} + \frac{E_{SC}}{COP} \right)}{\eta_{Grid}} + \frac{E_{SH}}{\eta_{Gas\ Heater}}$$

In separate generation the following were assumed:

- the DHW supply is provided by an electric water heater having an electrical efficiency, η_{Water} ***(85%)***
- the space heating is provided by an LPG gas heating system having an efficiency, $\eta_{Gas\ Heater}$ ***(85%)***
- the space cooling is provided by a vapour compression chiller with a Coefficient of Performance, ***COP (3)***
- the grid efficiency, η_{Grid}, is a variable parameter ***(25%-40%)***

$$PES = \frac{\left(PE_{SEPERATE} - PE_{\mu TRIGEN} \right) * 100}{PE_{SEPERATE}}$$

Environmental Performance Assessment

Measured metrics

- Micro-trigeneration system carbon footprint (e_{LPG} - *emission factor LPG)*

$$Emissions_{\mu TRIGEN} = e_{LPG} * PE_{\mu TRIGEN}$$

- Emissions emitted to produce equivalent energy required in separate generation - Variable $\boldsymbol{e_{Grid}}$ to simulate improvement in grid network

$$Emissions_{SEPERATE} = e_{Grid}\left(\frac{E_{DHW}}{\eta_{Water}} + E_{Net\ Demand\ \mu TRIGEN} + E_{Net\ Export} + \frac{E_{SC}}{COP}\right) + e_{LPG}\left(\frac{E_{SH}}{\eta_{Gas\ Heater}}\right)$$

- Emissions Savings

$$ES = \frac{\left(Emissions_{SEPERATE} - Emissions_{\mu TRIGEN}\right) * 100}{Emissions_{SEPERATE}}$$

Financial Performance Assessment (1)

Measured metrics

- ***Present Worth (PW)*** of the system, after ***Y*** years assuming an initial investment ***I*** and a minimum attractive rate of return of ***MARR***%

$$PW = -I + \sum_{y=1}^{y}\left(\frac{CF}{(1+MARR)^{y}}\right)$$

- ***Internal Rate of Return (IRR)***, for which the investment rate ***IR*** gives a ***PW*** of 0

$$IRR = IR\ for\ PW = -I + \sum_{y=1}^{y}\left(\frac{CF}{(1+IR)^{y}}\right) = 0$$

- ***Payback Period (PP)*** to start having a return on the investment

$$PP = \frac{I}{CF}$$

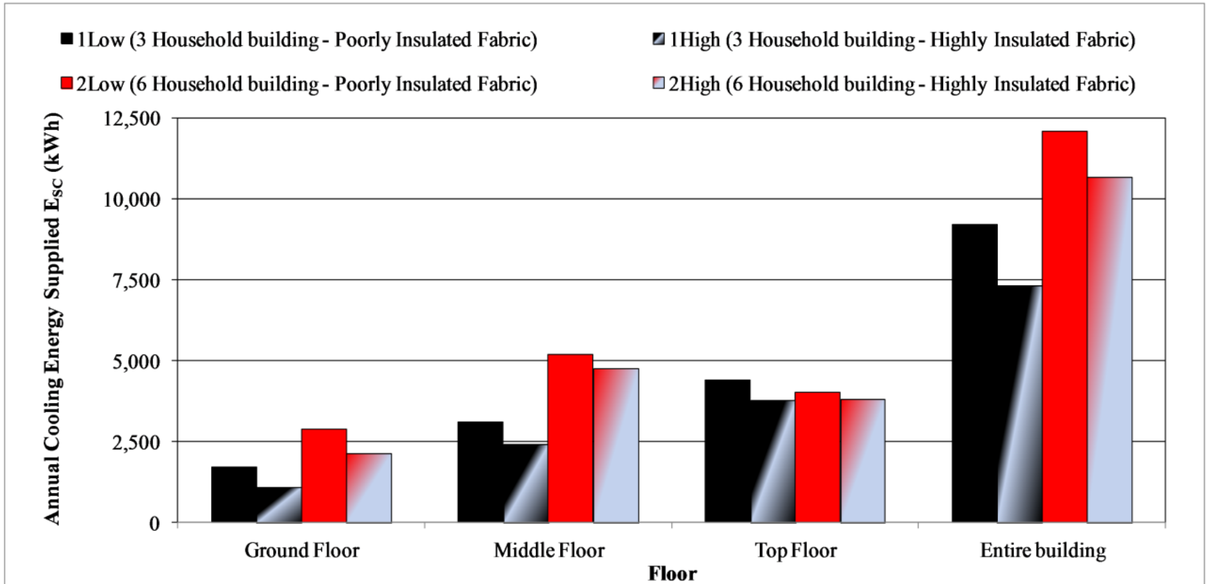
Financial Performance Assessment (2)

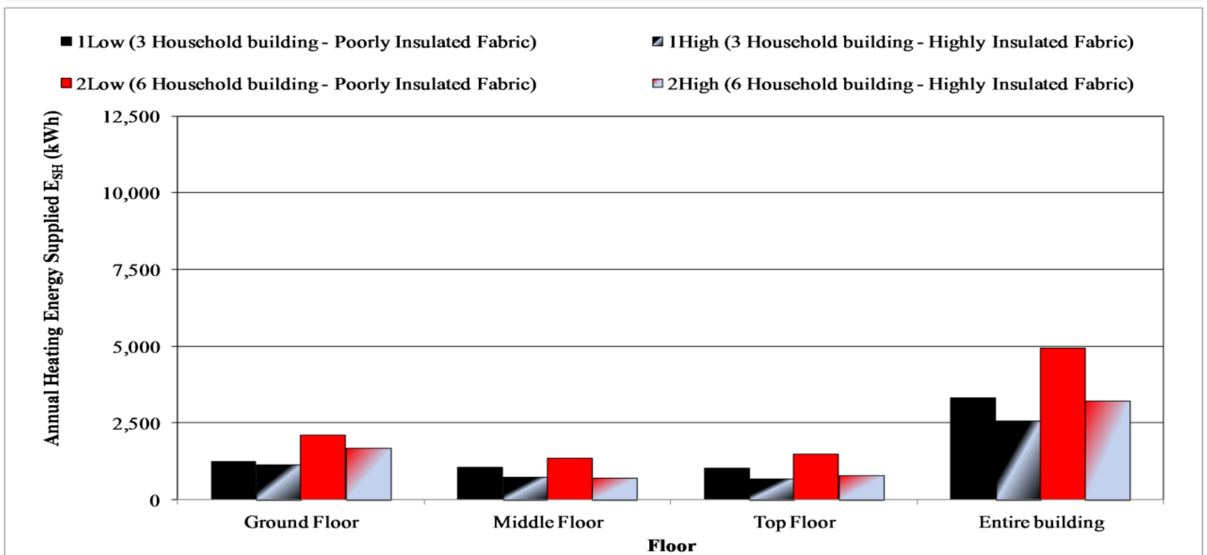
Cash Flow (CF) of the project

$$CF = E_{Net\ Export} * FIT + E_{Total} * Tariff - E_{Net\ Import} * Tariff - (E_{Net\ Export} + E_{Net\ Demand\ \mu TRIGEN}) * MC - (Fuel_{\mu TRIGEN} - Fuel_{SEPERATE}) * Cost\ of\ Fuel$$

Financial component	Explanation
$E_{Net\ Export} * FIT$	**Revenue from net export sales:** A source of income is the sale of electricity to the grid at the agreed *FIT*
$E_{Total} * Tariff$ $E_{Total} = \frac{E_{DHW}}{\eta_{water}} + \frac{E_{SC}}{COP} + E_{Net\ Import} + E_{Net\ Demand\ \mu TRIGEN}$	**Total invoiced electricity *without* trigeneration:** Assuming no micro-trigeneration system, E_{Total} includes the cost of all the electricity which would have otherwise been purchased through conventional separate generation sourced electricity
$E_{Net\ Import} * Tariff$	**Total invoiced electricity *with* trigeneration:** If a micro-trigeneration system is present, only the net electrical imports need to be purchased through separate generation sourced electricity
$(E_{Net\ Export} + E_{Net\ Demand\ \mu TRIGEN}) * MC$	**Maintenance cost:** The maintenance cost is calculated by multiplying the electricity produced by the CHP by the maintenance cost rate (*MC*) in €/kWh produced
$(Fuel_{\mu TRIGEN} - Fuel_{SEPERATE}) * Cost\ of\ Fuel$	**Fuel purchasing costs:** Calculated by deducting the amount of fuel which would have been used by the space heating in separate generation from the total fuel used by the micro-trigeneration system and multiplying the net amount of fuel by the fuel cost

Energetic Performance Results (1) – Heating & Cooling

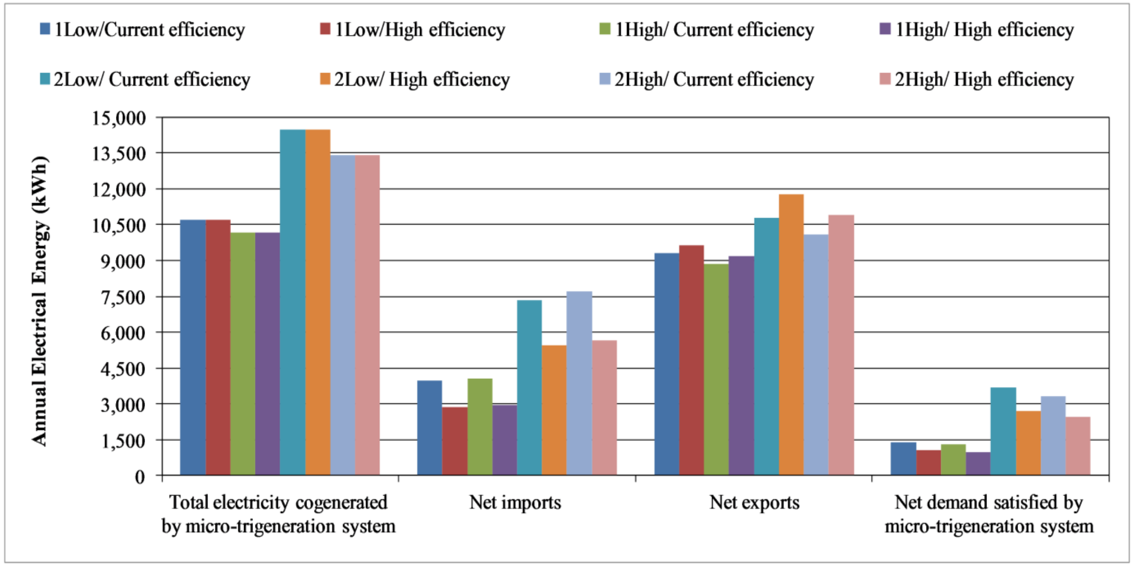


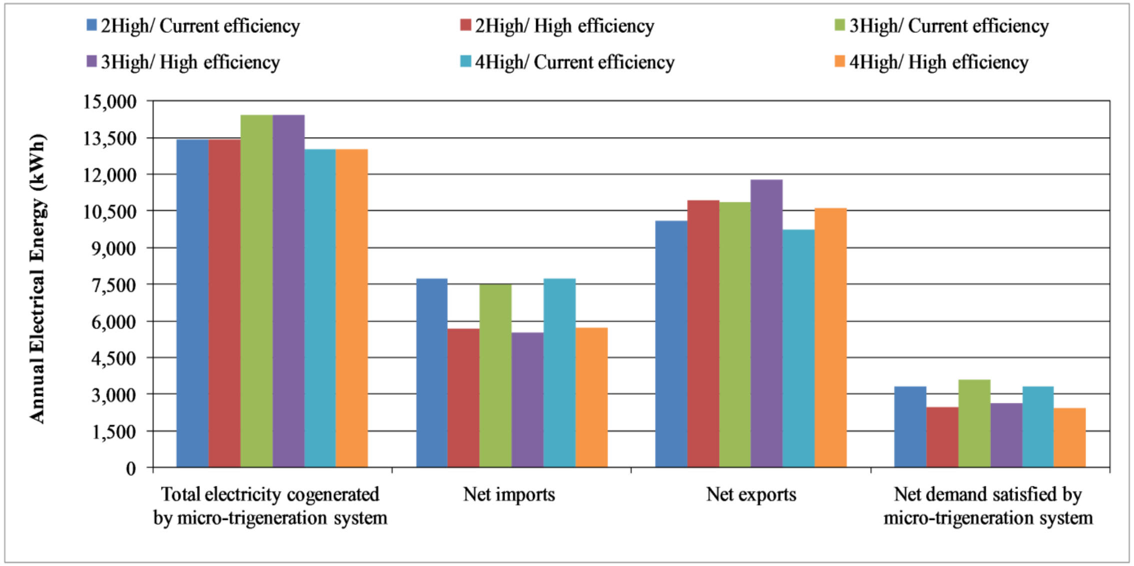


Annual space heating (E_{SH}) and space cooling (E_{SC}) energy supplied to the 3 households building (Scenarios 1_{Low} and 1_{High}) and the 6 households building (Scenarios 2_{Low} and 2_{High}) for the poorly and high insulated building fabric scenarios

Scenario groups 3_{High}, 4_{High} and 5_{High} show identical results to the results obtained for Scenario 2_{High}

Energetic Performance Results (2) – Electrical Performance





Scenarios 1 & 2

✓ For the same household appliances' electrical efficiency, improving the building fabric results in:

- A reduction in cogenerated electricity;
- An increase in electrical imports;
- A reduction in exports; and
- A reduction in demand satisfied by *μTrigen*

✓ For the same building fabric, improving the household appliances' electrical efficiency does not effect the amount of cogenerated electricity but results in:

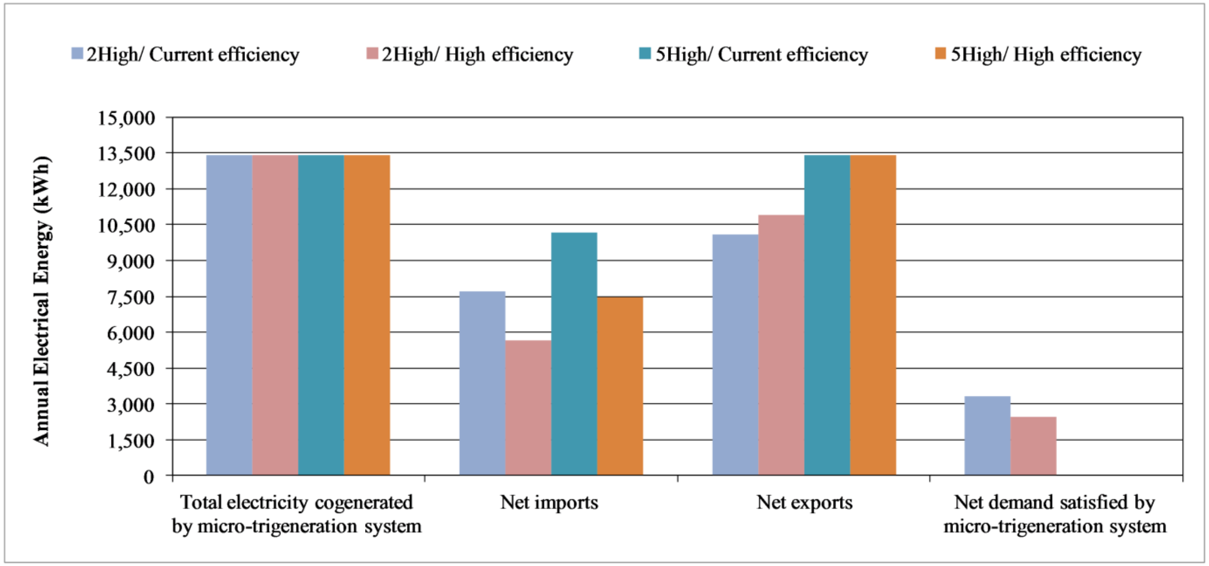
- A reduction in electrical imports;
- A reduction in demand satisfied by *μTrigen;* and
- An increase in exports

Different plant configurations

✓ Reducing the system operating hours (*e.g.* additional SWH) lowers the amount of cogenerated electricity, resulting in higher imports, lower exports and a lower demand satisfied by *μTrigen*

✓ Increasing the system operating (*e.g.* additional chilled water tank) increase the amount of cogenerated electricity, resulting in lower imports, higher exports and a higher demand satisfied by *μTrigen*

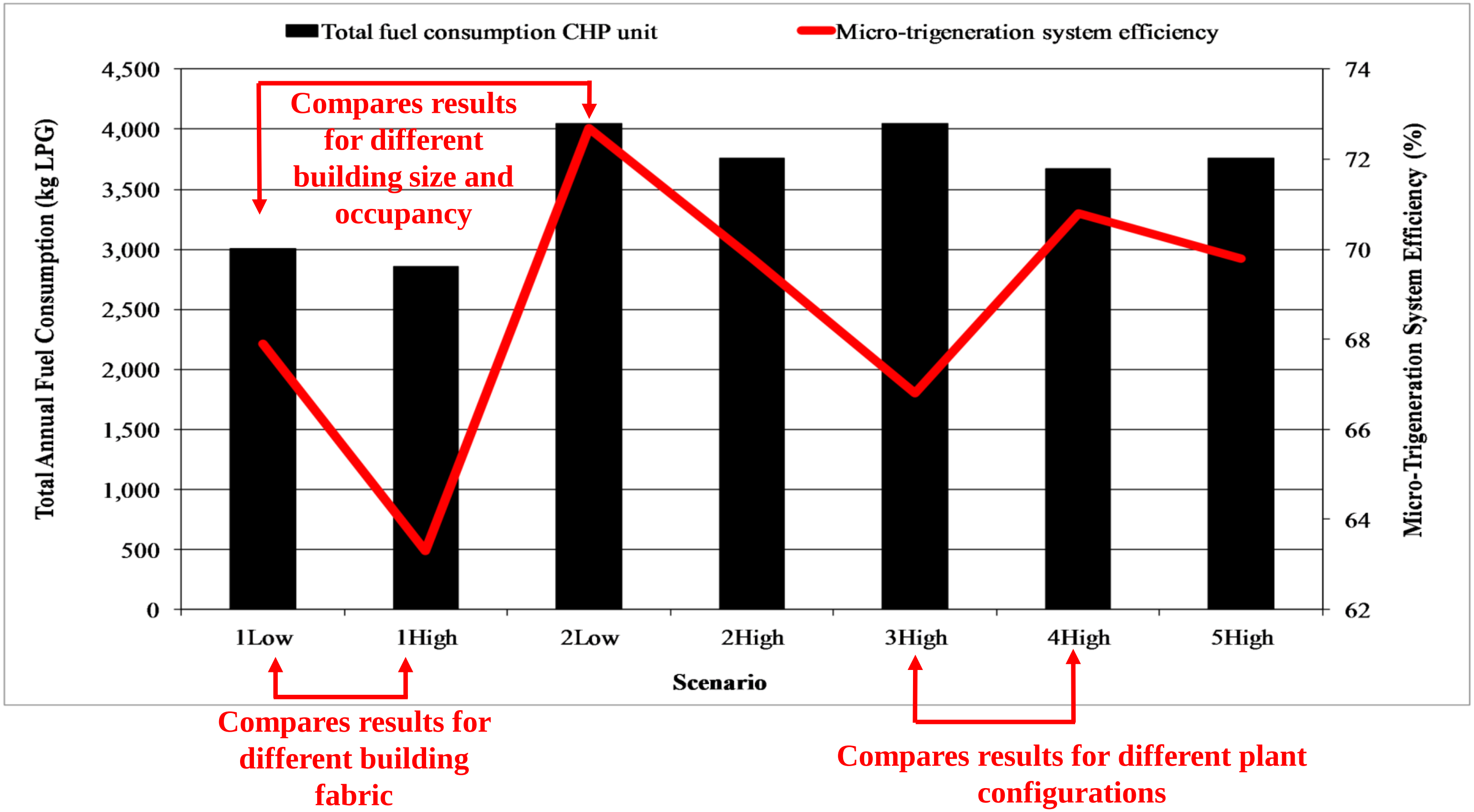
Energetic Performance Results (3) – Electrical Performance



Scenarios 2 and 5

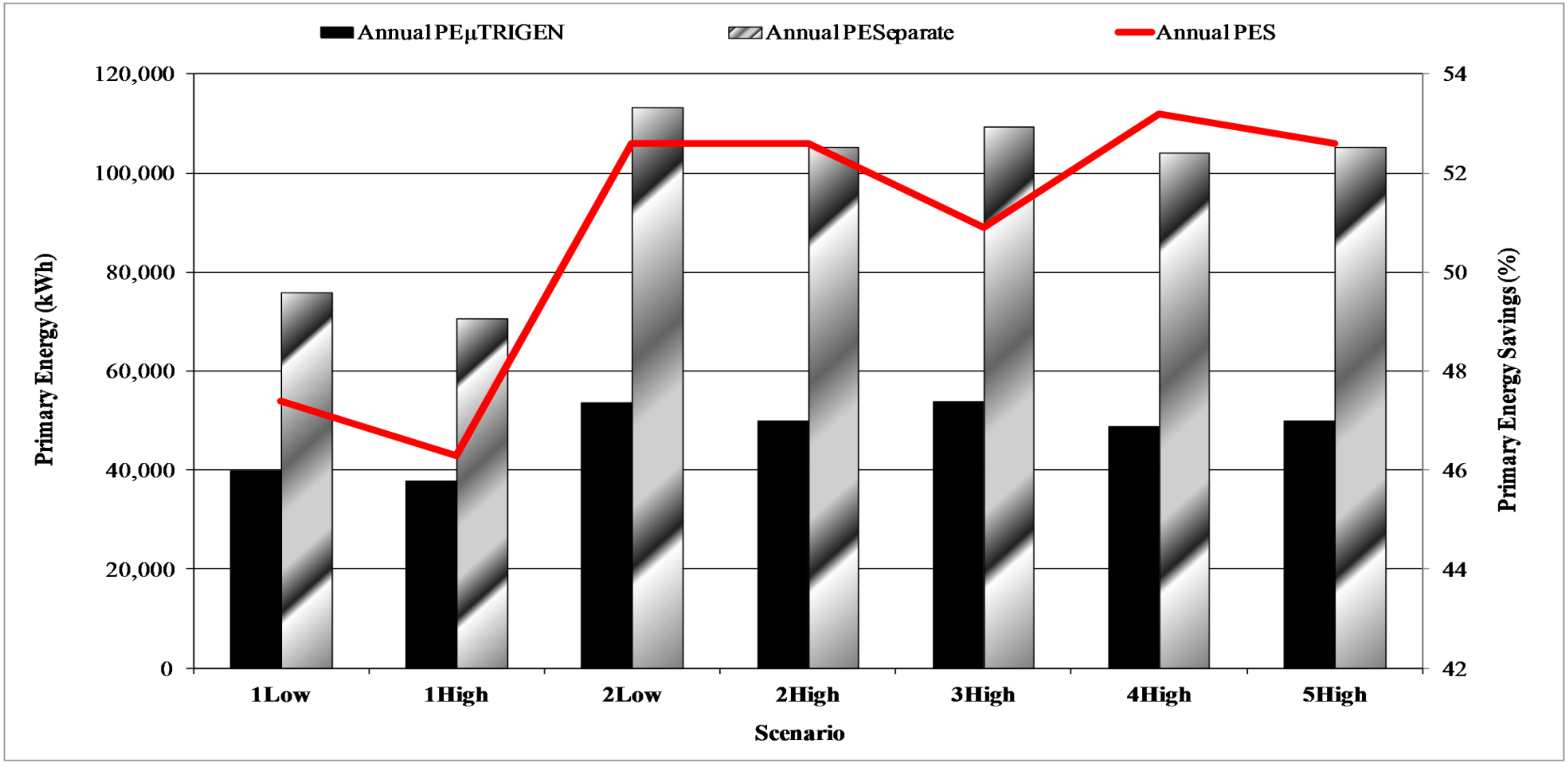
- ✓ Same amount of cogenerated electricity (same plant configuration and same conditions)
- ✓ Difference in use as all cogenerated electricity is exported (Preffered option based on *FIT* price compared to grid electricity tariff)
- ✓ Does not effect energetic or environmental performance but effects the financial value of the system

Energetic Performance Results (4) – Fuel Consumption & Efficiency



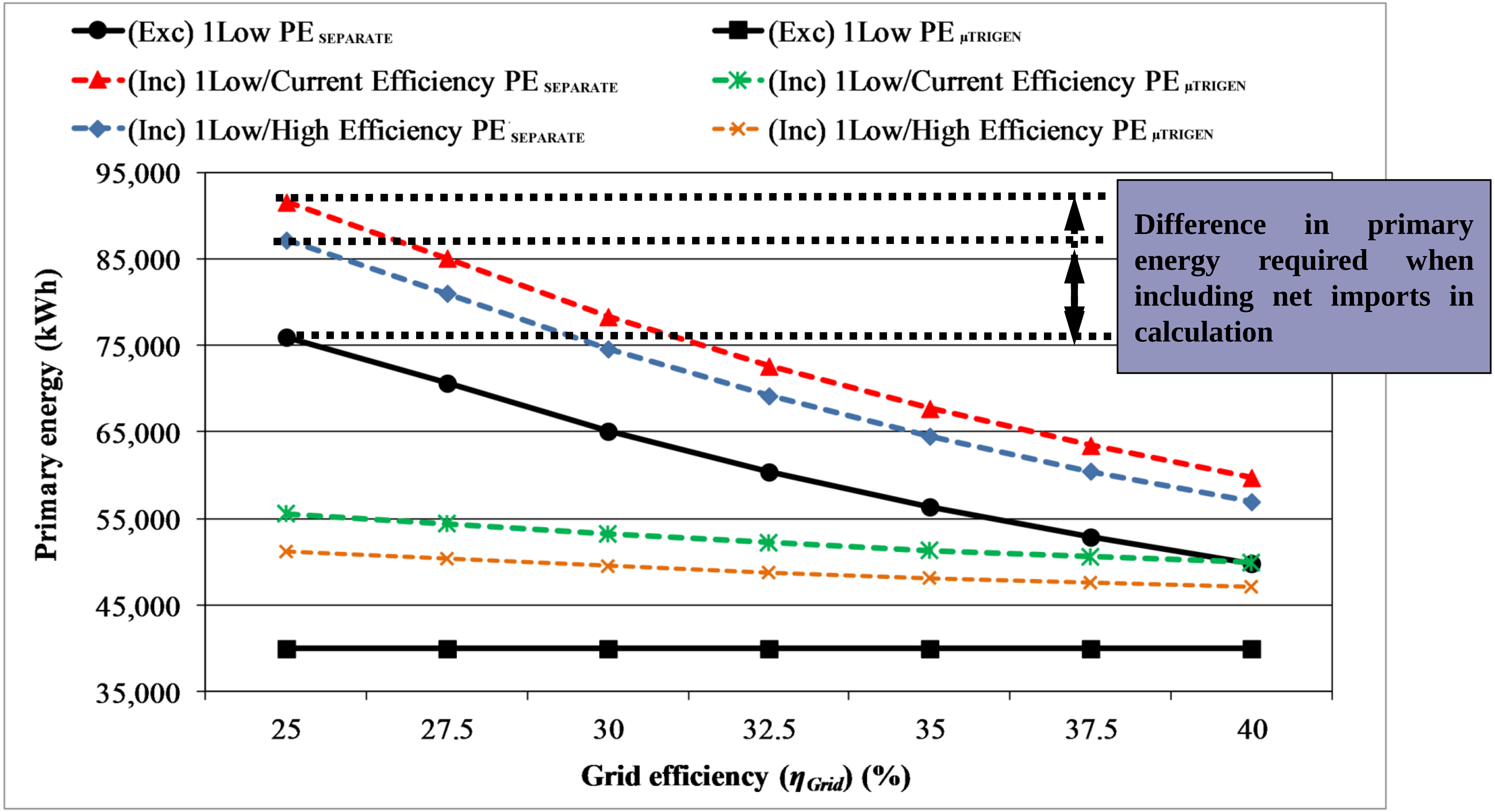
- Annual CHP fuel consumption and system efficiency for the different scenarios
- Improving the building fabric reduces the efficiency
- For the same building fabric, the household appliances' electrical efficiency does not change the thermal performance of the system
- On a seasonal basis, the micro-trigeneration system is most efficient in the cooling season

Energetic Performance Results (5) – Primary Energy



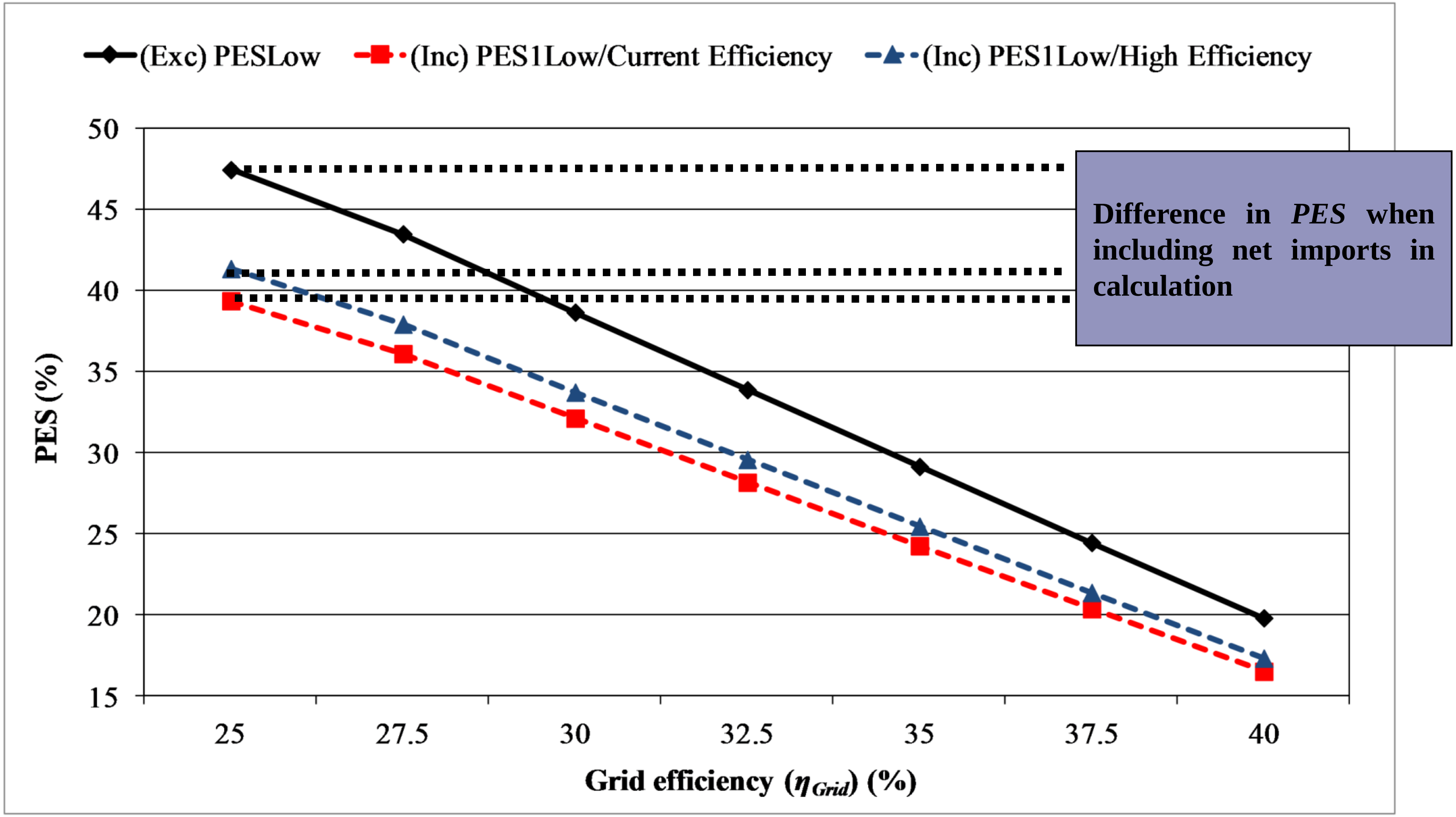
- Values exclude additional primary energy required to cover for net electrical imports ($E_{Net\ Import}$)
- If the net imports are not included, the thermal performance, the cogenerated electricity and hence the *PES* is the same for both household appliances' electrical efficiency (current & high efficiency)
- Lower system efficiency results in lower *Primary Energy Savings* (*PES*)

Energetic Performance Results (6) – Improving grid efficiency



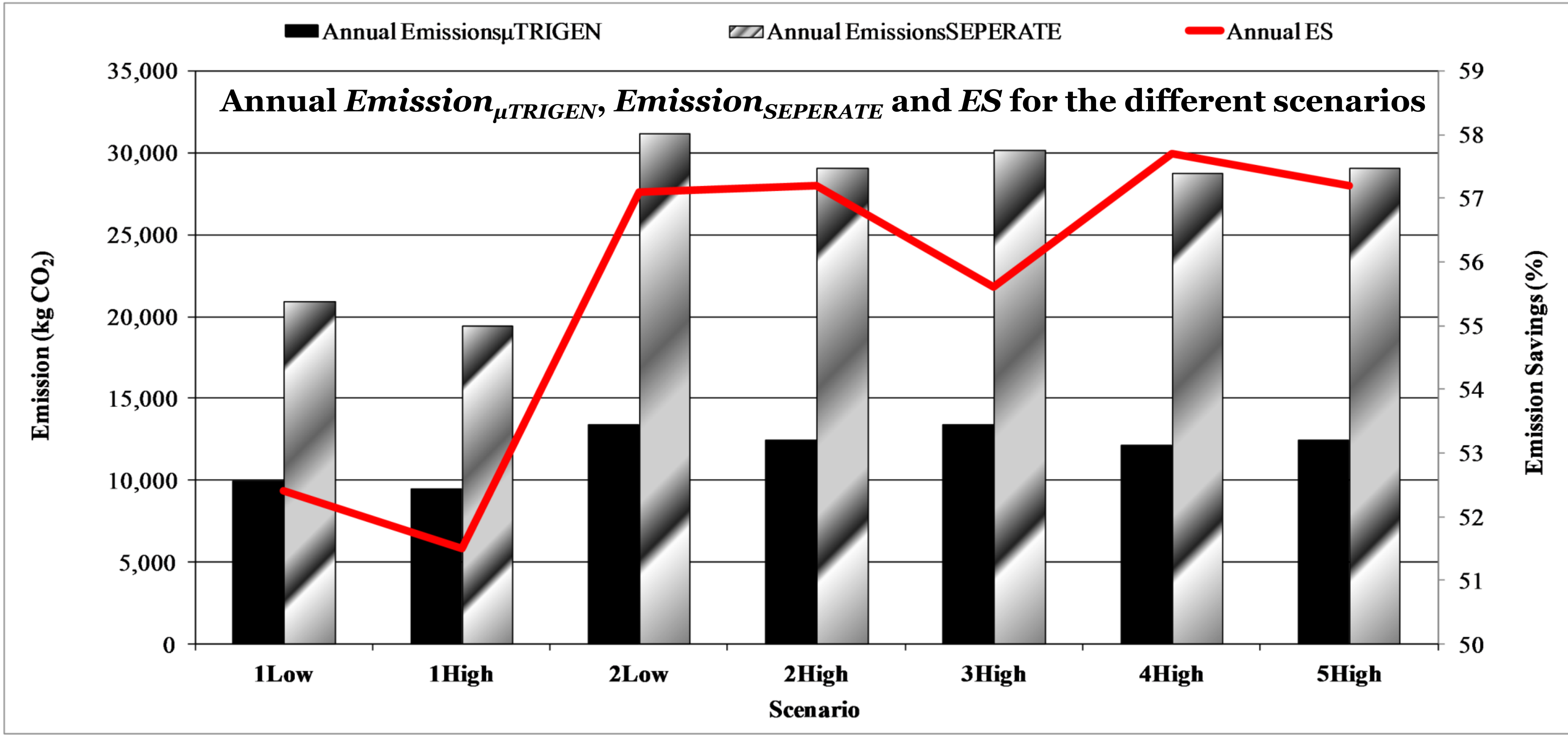
Improvements carried out to increase the electrical efficiency of the grid would result in making separate generation more efficient, requiring less primary energy and consequently making the micro-trigeneration system less energetically advantageous

Energetic Performance Results (7) – Improving grid efficiency (effect on PES)



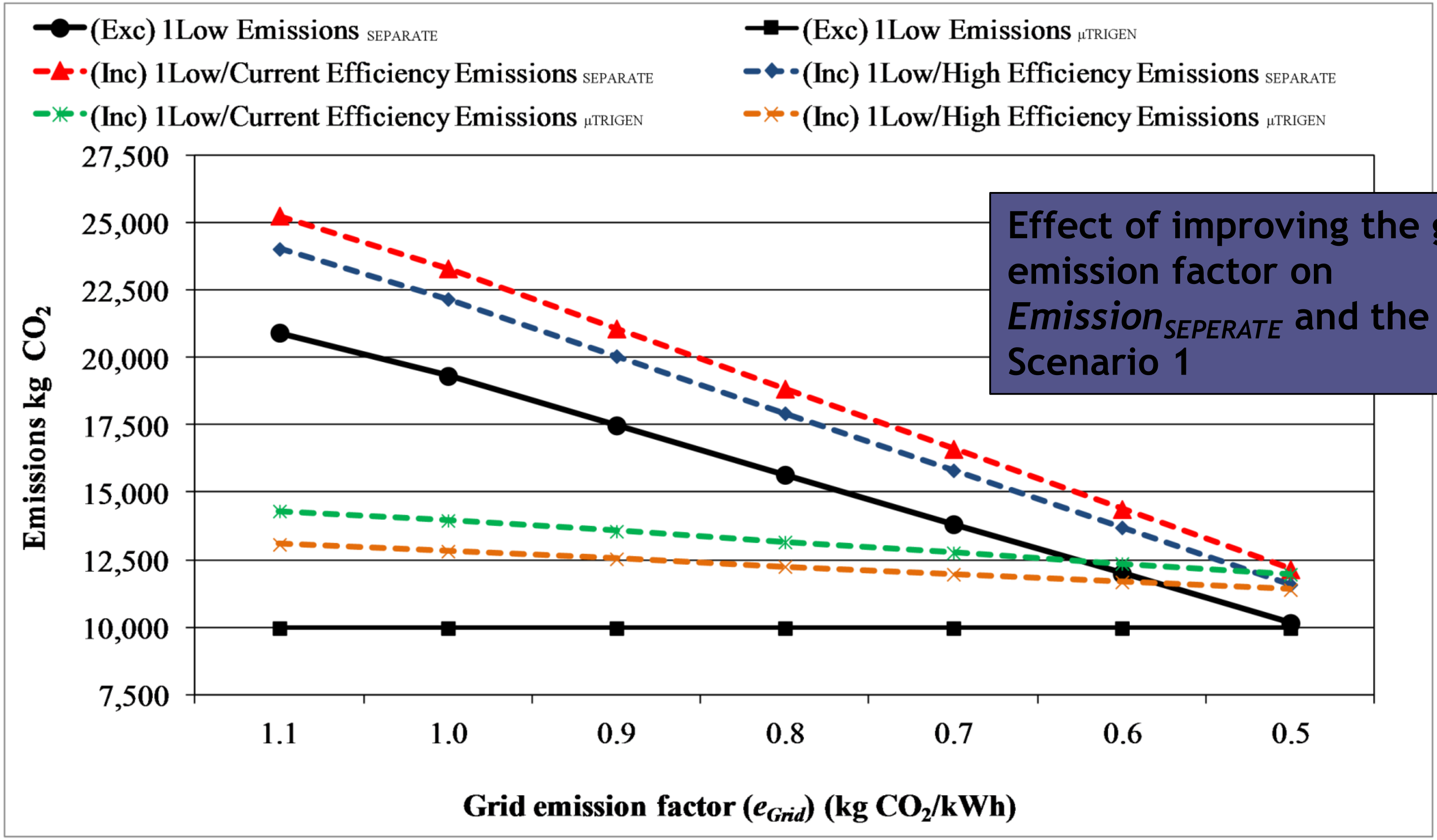
- ✓ **Improving the grid electrical efficiency, *PES* is reduced**
- ✓ **Also, improving the grid electrical efficiency the different calculated *PES* (*i.e.* including and excluding net electrical imports) converge - Difference in primary energy required to produce the additional electrical imports diminishes**

Environmental Performance Results (1) - Emissions



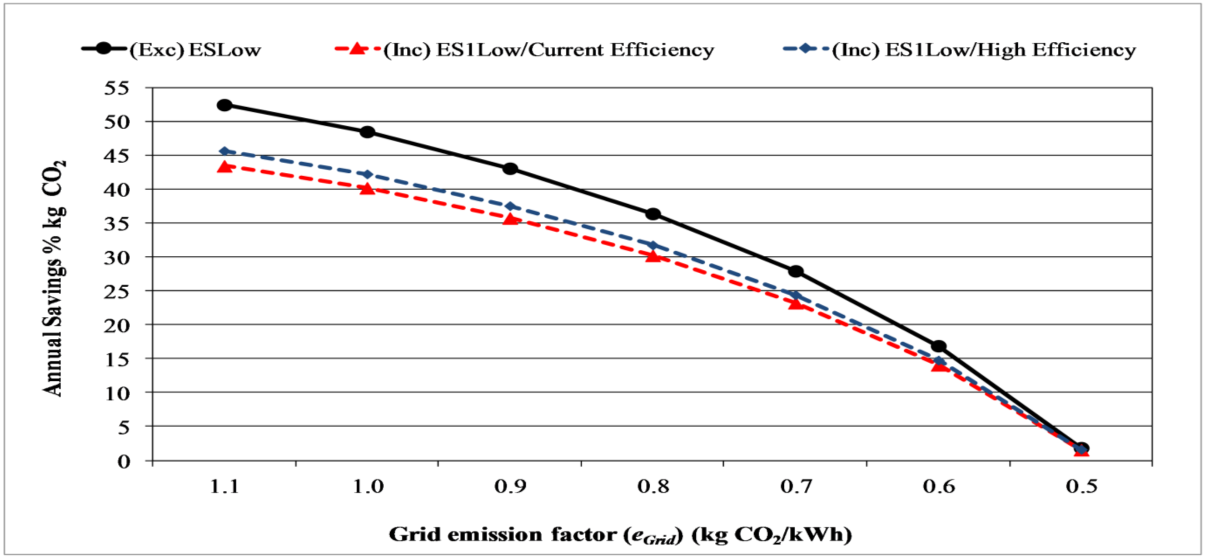
- Reducing the system's operational hours by reducing the useful thermal load (*e.g.* Improving the building fabric, lower occupancy, *etc*.) results in a lower *ES (Emission Savings)*
- The additional chilled water tank system configuration in System 3_{High} is the plant system with the lowest *ES* value. On the contrary, the additional flat plate SWH, renders the system used in Scenario 4_{High}, the scenario with the highest *ES* value

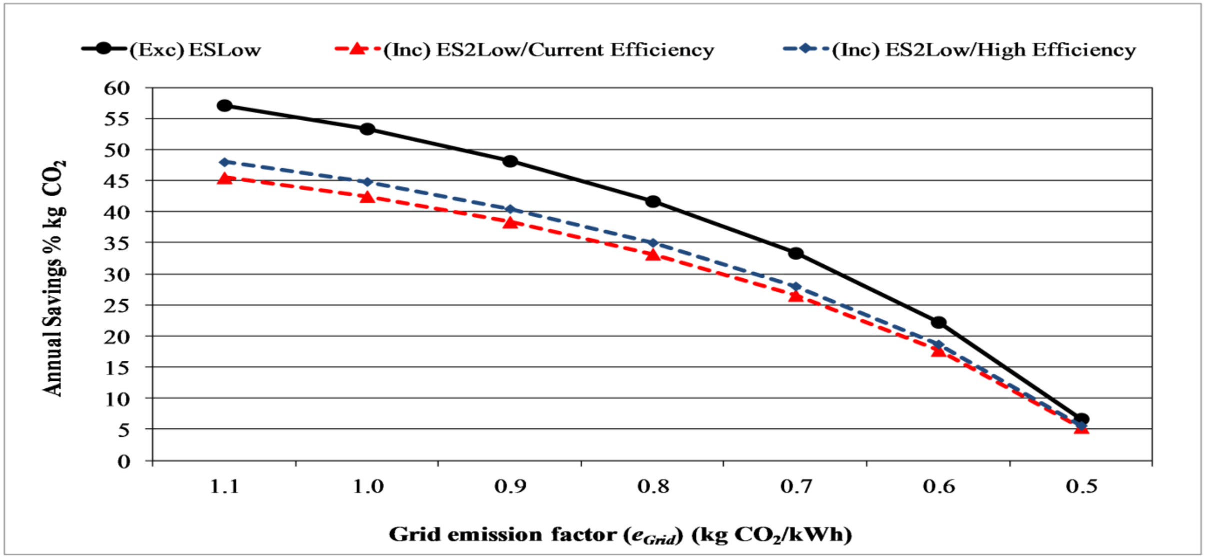
Environmental Performance Results (2) - Improving grid emissions



Effect of improving the grid emission factor on $Emission_{SEPERATE}$ and the *ES* of Scenario 1

Environmental Performance Results (3) - Improving grid emissions





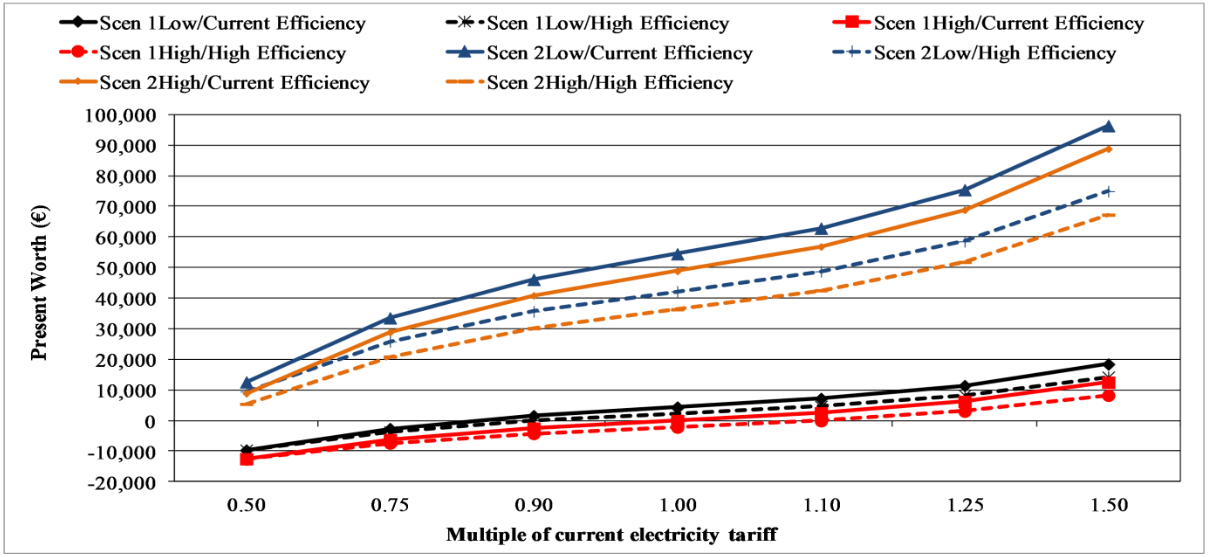
Improving the grid emission factor results in a reduction in emissions produced in separate generation, $Emissions_{SEPARATE}$, with a subsequent reduction in the micro-trigeneration system environmental advantage

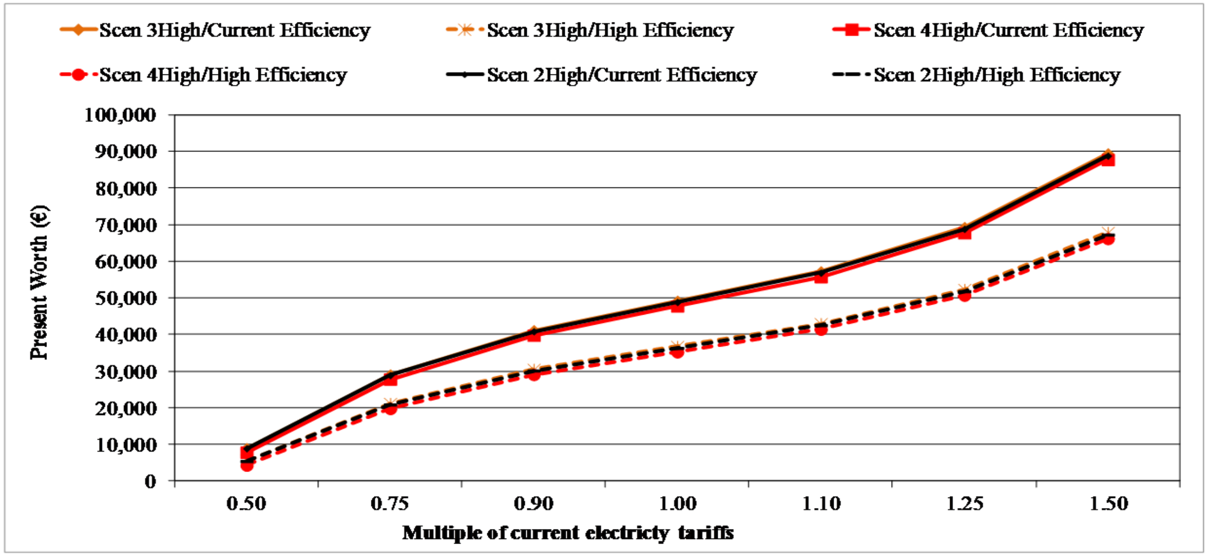
For the 3 household building, e_{Grid} equal to 0.5, appears to be the environmental limit beyond which using a *μTrigen* loses any environmental advantage over separate generation

The 6 household building shows a similar behaviour although compared to the 3 household building it partially retains its environmental advantage

Financial Performance Results (1) – Present Worth (1)

Varying electricity tariff / Constant gas price





Scenarios 1 & 2

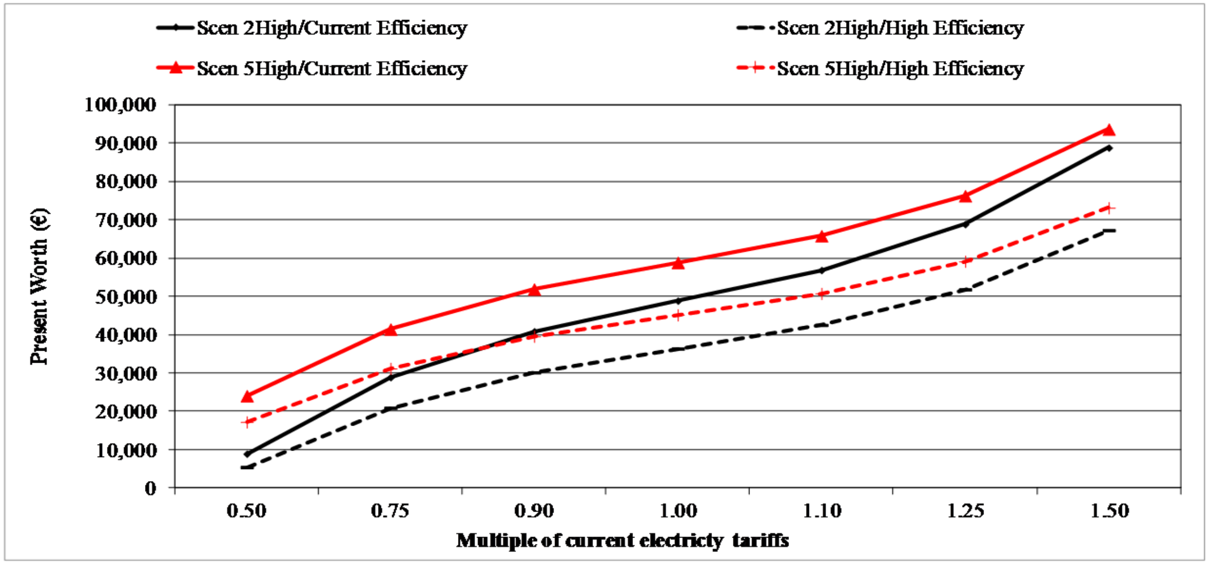
- Assuming a constant *FIT* (0.5 €/kWh) and gas price (1.19 €/kg), with an increasing electricity tariff, the *PW* of the project increases - At low electricity tariffs, small projects are not financially viable
- Reducing the electrical demand (by improving the electrical efficiency of appliances) and reducing the thermal demand (by improving the building fabric) results in a reduction in the project's *PW*
- With higher electricity tariffs the difference between the scenarios increases in response to the scenario's different cash flow

Different plant configurations

- The proposed plant configurations modification do not alter the financial value of the system

Financial Performance Results (2) – Present Worth (2)

Varying electricity tariff / Constant gas price

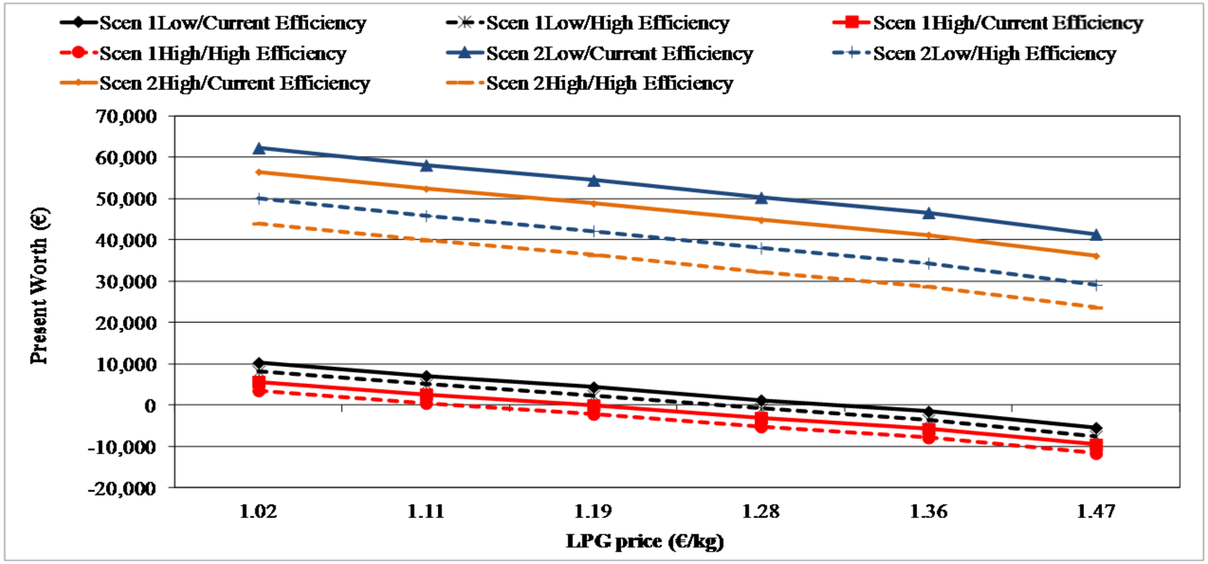


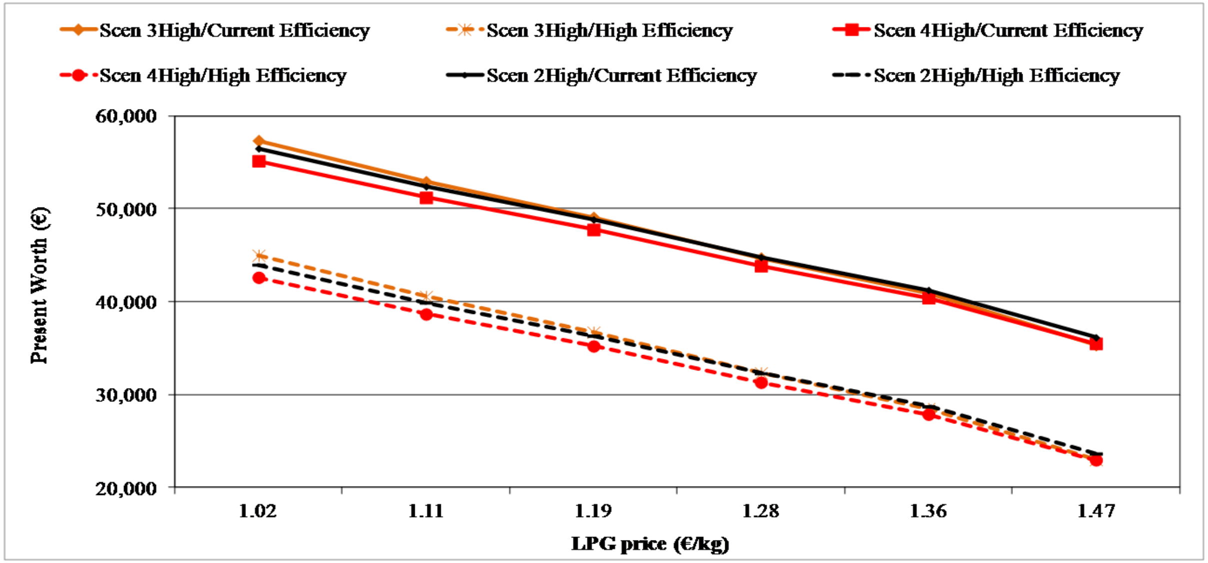
Scenarios 2 & 5

- At the given conditions exporting the entirety of the cogenerated electricity makes the project more economically feasible, especially at low electricity tariffs

Financial Performance Results (3) – Present Worth (3)

Varying gas price / Constant electricity tariff





Scenarios 1 & 2

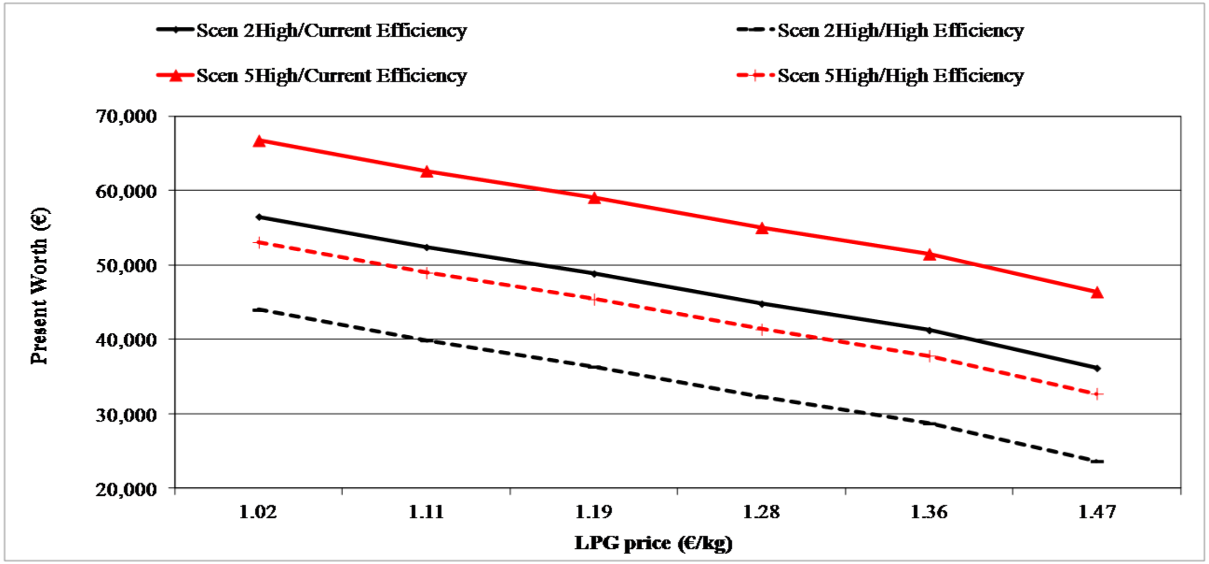
- Assuming a constant *FIT* (0.5 €/kWh) and electricity tariffs, with increasing gas prices, the *PW* of the project diminishes - At high gas prices, small projects are not financially viable
- Reducing the electrical demand (by improving the electrical efficiency of appliances) and reducing the thermal demand (by improving the building fabric) results in a reduction in the project's *PW*
- Difference between scenarios is constant

Different plant configurations

- The proposed plant configurations modification do not alter the financial value of the system

Financial Performance Results (4) – Present Worth (4)

Varying gas price / Constant electricity tariff



Scenarios 2 & 5

- At the given conditions exporting the entirety of the cogenerated electricity makes the project more economically feasible, especially at low electricity tariffs

Summary Research Outcomes

Specific results for the different scenarios modelled and simulated – Understanding the effects of different operating conditions on the performance of micro-trigeneration in residential buildings, such as:

- ✓ Compared to separate generation expected **annual PES savings of about 38-44%** / **annual emission savings of about 42-47%** (depending on scenario)
- ✓ Improving the **building fabric** equates to a lower operating load factor of the micro-trigeneration system which leads to a deterioration of the system's energetic, environmental and economic performance
- ✓ **Electrical efficiency improvements** in household appliances proved to be effective in reducing the electrical energy consumption but not necessarily in reducing peak demands in individual or small aggregation of households. Reducing the overall electrical demand (including net imports) of the building leads to an improvement in the system's primary energy and annual CO_2 savings but in a deterioration in the economic performance of the system
- ✓ On such a micro-scale **different plant configuration** affect the energetic and environmental performance of the system but do not affect the systems' economic performance. Depending on the type of plant modification, system operation such as cycling 'On'/'Off' is severely affected
- ✓ Properly **matching plant sizing** with the building energy demand is very important. At low electricity tariffs or high fuel costs, oversizing a system may lead to the system's unfeasibility
- ✓ The financial performance of the system for all scenarios increases with increasing **electricity tariffs** and decreases with increasing **LPG Prices**, although to varying degrees depending on the particular case for each scenario
- ✓ **Grid network decarbonisation** severely effect system performance

Summary Research Outcomes

Performance	*Energetic*							*Operational*	*Environmental*	*Financial*		
Operational Condition	*μTrigen fuel consumption*	*Effect on electrical performance*				*System efficiency ($\eta_{\mu TRIGEN}$)*	*Primary energy savings (PES)*	*CHP Unit 'On'/'Off' Cycling*	*Emission savings (ES)[9]*	*Present worth (PW)*	*Internal rate of return (IRR)*	*Payback period (PP)*
		μTrigen cogenerated electricity	*Net imports*	*Net exports*	*Net demand satisfied by μTrigen*							
Building fabric improvement	Decreased (Improved)	Decreased (Deteriorated)	Increased (Deteriorated)	Decreased (Deteriorated)	Decreased (Deteriorated)	Decreased (Deteriorated)	Decreased (Deteriorated)	Variable (Depends on scenario)	Decreased (Deteriorated)	Decreased (Deteriorated)	Decreased (Deteriorated)	Increased (Deteriorated)
Increased building size and occupancy	Increased (Deteriorated)	Increased (Improved)	Increased (Deteriorated)	Increased (Improved)	Increased (Improved)	Increased (Improved)	Increased (Improved)	Decreased (Improved)	Increased (Improved)	Increased (Improved)	Increased (Improved)	Decreased (Improved)
Addition of a chilled water storage tank	Increased (Deteriorated)	Increased (Improved)	Decreased (Improved)	Increased (Improved)	Increased (Improved)	Decreased (Deteriorated)	Decreased (Deteriorated)	Decreased (Improved)	Decreased (Deteriorated)	Negligible change	Negligible change	Negligible change
Appliances electrical efficiency improvement	Criterion not affected	Criterion not affected	Decreased (Improved)	Increased (Improved)	Decreased (Deteriorated)	Criterion not affected	Increased (Improved)	Criterion not affected	Increased (Improved)	Decreased (Deteriorated)	Decreased (Deteriorated)	Increased (Deteriorated)
Addition of SWH to the μTrigen system	Decreased (Improved)	Decreased (Deteriorated)	Increased (Deteriorated)	Decreased (Deteriorated)	Decreased (Deteriorated)	Increased (Improved)	Increased (Improved)	Decreased (Improved)	Increased (Improved)	Negligible change	Negligible change	Negligible change
Grid network improvement	Criterion not affected	Criterion not affected	Criterion not affected	Criterion not affected	Criterion not affected	Criterion not affected	Decreases (Deteriorated)	Criterion not affected	Decreases (Deteriorated)	Criterion not affected	Criterion not affected	Criterion not affected
All cogenerated electricity is exported	Criterion not affected	Criterion not affected	Increased (Deteriorated)	Increased (Improved)	Decreased (Deteriorated)	Criterion not affected	Decreases (Deteriorated)	Criterion not effected	Decreases (Deteriorated)	Increased (Improved)	Increased (Improved)	Decreased (Improved)
Increase in electricity tariff	Criterion not affected	Criterion not affected	Criterion not affected	Criterion not affected	Criterion not affected	Criterion not affected	Criterion not affected	Criterion not affected	Criterion not affected	Increased (Improved)	Increased (Improved)	Decreased (Improved)
Increase in LPG price	Criterion not affected	Criterion not affected	Criterion not affected	Criterion not affected	Criterion not affected	Criterion not affected	Criterion not affected	Criterion not affected	Criterion not affected	Decreased (Deteriorated)	Decreased (Deteriorated)	Increased (Deteriorated)

[1] Analysis of *PES* and *ES* includes the net electrical imports in the calculation.
[2] Fuel consumption increases if the entire building is considered - per household the micro-trigeneration system fuel consumption decreases.

Thank You

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