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INTRODUCTION

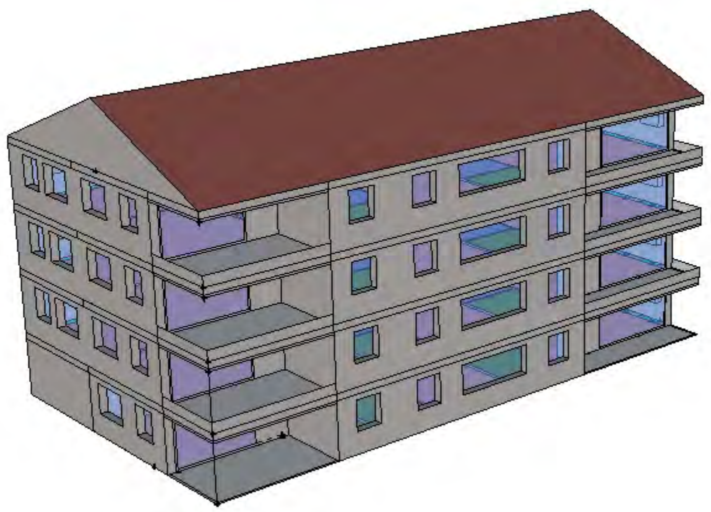
In order to better understand how to maximize the energy saving potential throughout a renovation process, and in the context of the Energy Performance of Building Directives (EPBD) revision, one essential question is how to prioritise actions in the renovation cycles.

In order to raise the understanding of the respective contributions of passive (envelope improvement) and active (heating and cooling equipment, controls) technologies, a detailed thermal study has been fulfilled by TRANSSOLAR. This study has been completed by TRIBU ENERGIE which report is in the Annex III of the document with a thorough economic assessment of the main refurbishment strategies, specifically for residential buildings.

This work uses numerical thermal modeling with the TRNSYS software package to model a standard residential building, under three different climates, with different envelope performance, control strategies, and heating and cooling equipment. For each variant, numerous outputs are calculated in order to understand the respective contributions of each refurbishment solution in terms of:

- Energy demand
- Energy consumption (final and primary)
- CO2 emissions
- Thermal comfort
- Life cycle cost (Tribu study)

Main refurbishment strategies, involving successive refurbishment actions, are compared in order to understand which sequence of measures achieves the best overall performance improvement.



METHODOLOGY

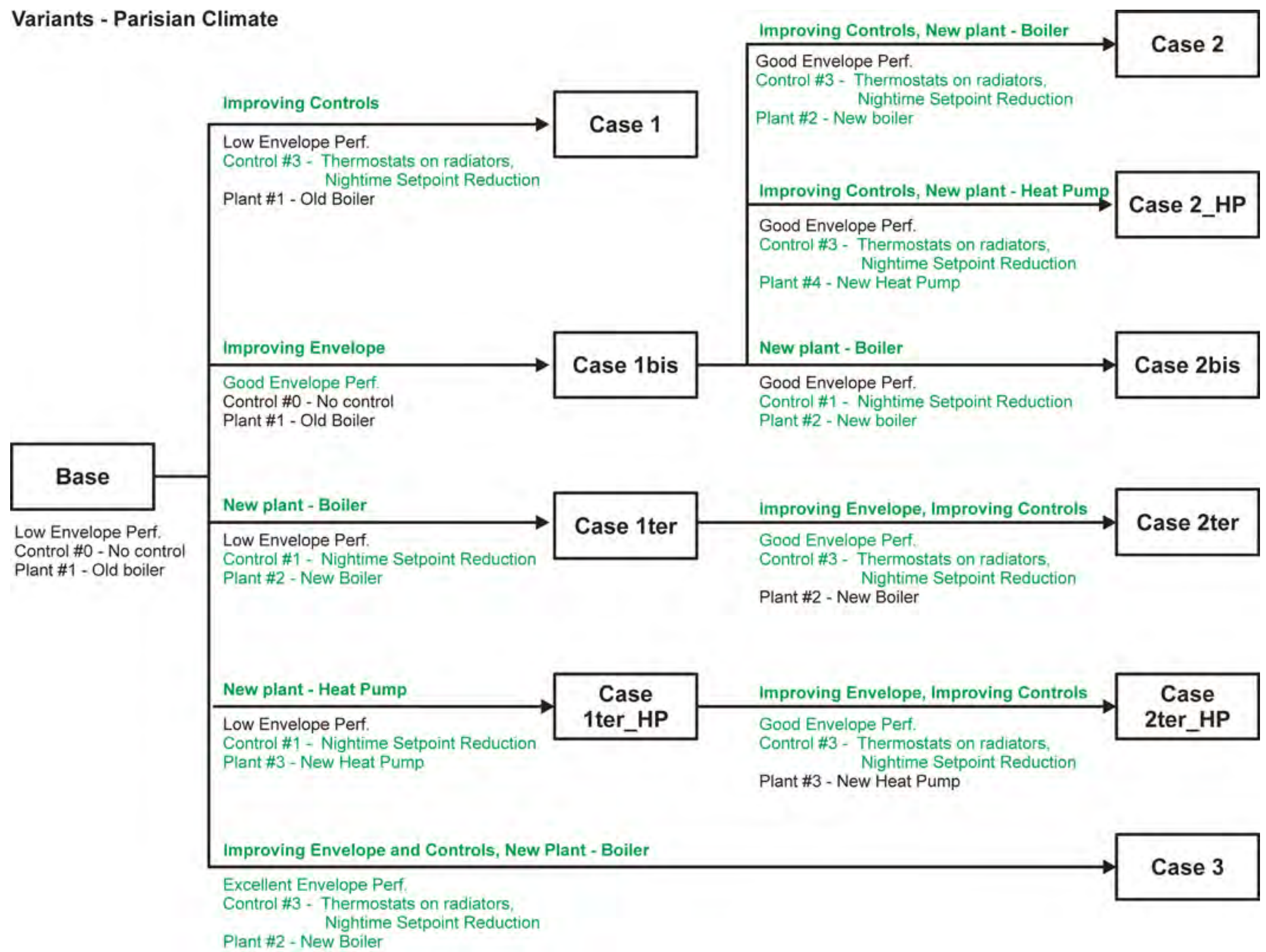
The boundary conditions for the present study are detailed in Annex II. The assumptions of the study have been defined so as to give as much as possible a realistic European picture, these are:

Type of building.

We considered the renovation of a multi-family building (MFD) in 3 different European climatic regions (Paris, Helsiniki, Napels) with the objective to define the potential at the level of energy consumption, global warming potential, economic impacts and comfort. The reason for choosing a MFD is that it represents a typical building type across the EU while capturing different consumer behaviours and demographics.

Level of renovation.

There are three levels of renovation and a base case which represents a building from the current building stock. A first series of calculations case 1 is representing a renovation to a good level but only for the building envelope or for the equipment. In the calculations of case 2 the renovation is completed on the good level with respectively the equipment or the building envelope. All case 2 calculations have though both an improved building envelope and an improved equipment. A non-stepwise renovation to case 3 has also been assessed. Case 3 has been put at the level of NZEB (for a renovated building) .



No on-site renewables have been assessed.

In all the studied cases it would be possible to add some on-site renewables. The share of the total consumption that can be covered by renewables will be depending of the energy demand. The lower the energy demand, the higher the part that could be covered by renewables.

The simulation modeling is done following a two steps approach. First the apartment spaces are modeled in order to calculate the building energy needs (heating, cooling, domestic hot water, electricity). Then, the heating system is modeled dynamically to assess its equipment thermal behavior and its energy consumption.

TRIBU ENERGIE's cost analysis focuses on three main refurbishment strategies and reuses TRANSSOLAR's thermal modeling results. The analysis covers energy costs, investment costs and maintenance costs over a 50 years span.

SUMMARY

The only way of reducing significantly the operating and the global costs due to building energy consumptions in the medium term, and even more in the long term (more than 20 to 25 years), is to make an envelope renovation. The gain on operating costs due to insulation is about 50%, while it is lower than 20% for system improvements. Improvements only related to thermostats and/or boilers enable to get short returns on investments, but are not very economical in the long term because final energy consumptions, and therefore operating costs, remain high.

The improvements concerning the renovation of the envelope give rise to longer returns on investment, but as soon as the return on investment year is reached, they become to a great extent the best economic solution, because final energy consumptions are much lower than with a single heating system replacement.

For example, with the Paris climate, improving the existing envelope to a level comparable to a new construction would lead to a gas consumption reduction of 66%. In comparison, working only on the controls would bring a 25% reduction, and changing the boiler would involve a 30% gas consumption reduction.

When refurbishing the boiler, implementing a modulating burner helps to easily adapt the boiler to heating demand variations. Using an oversized new boiler with a modulating burner (high efficiency boiler) increases only by 1% the total gas consumption compared to a correctly sized one. This is due to the new modulating burner that is able to vary its instantaneous power in the range of 10% to 100% of its nominal power. In addition, the new boiler presents a nominal efficiency much higher than the elder one. For these reasons, the refurbishment order between the boiler and the envelope does not really impact the final energy consumption once both solutions have been applied.

However, refurbishing the envelope first would translate into a strong peak heating power reduction by 61% (-132 kW), which would limit the size of the next new boiler to be installed. As a consequence, investment costs, maintenance costs, and grey energy costs will be reduced. Also, with a “Boiler First” refurbishment strategy, as the plant equipment is generally oversized and despite being well-insulated, its generation and distribution losses are 45% higher (3.1 kWh/m²/y) than after the “Envelope First” refurbishment strategy.

Moreover, in some countries like France, if the boiler size is small enough (lower than 70kW), the fire safety regulations are reduced for the boiler room, which can translate into further investment and maintenance costs savings.

Installing a heat pump to replace the old boiler achieves the lowest final energy demand, thus the highest overall building’s efficiency, thanks to an efficient seasonal coefficient of performance. But to benefit from all the heat pump potential, the envelope has to be well-insulated. Otherwise, using a heat pump with a unrefurbished envelope requires to keep an existing boiler to handle high temperature regimes with low outside air temperature (cf chapter 1.8).

As thermal comfort is impacted by paramaters such as air and surface temperatures, a poorly insulated fabric can result in occupants having poorer thermal comfort perceptions. As a result they may be more likely to increase thermostat temperature points to counter act this, which will result in increased energy consumption. As a consequence, the energy savings related to improving the control strategies can’t be fully reached if the buidling envelope has not been improved. Otherwise, the room air temperature has to be kept at a high level to avoid low perceived temperature and building pathologies like condensation and mold. In comparison, with a better insulated envelope, cold wall effects are avoided which increases the felt temperature for the occupant by up to 3°C in Winter.

Refurbishing the envelope also leads to higher summer comfort thanks to better solar gain management. As an example, for the Parisian case, peak cooling power can be reduced by 50% which could also limit the impact on the local urban heat island effect.

When considering a heat wave scenario in Paris, thermal comfort without active cooling systems can only be achieved if the envelope has been well-refurbished. In this case, passive cooling strategies have to be implemented (night time ventilation, elevated air speed via ceiling fans, etc.) to extract internal heat gains and improve the occupant perceived temperature. In comparison, with a non-refurbished envelope, internal felt temperature can rise up to 32°C, which translates into thermal stress.

When comparing the energy results for the three different climates, heating energy demands reach similar levels despite different heating degree day values. This is why working on the combination of envelope and equipment makes sense in the 3 climatic regions in order to achieve an excellent energy performance. No climatic region can achieve this excellent energy performance without a well-thought interaction between envelope refurbishment and equipment refurbishment.

In conclusion, envelope improvements would allow reducing energy consumption and guaranteeing thermal comfort while the systems improvements will not produce an improvement of thermal comfort.

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With the contribution of:

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1. **Paris Comparison - Energy**

1.1. Results Summary (area specific)

BOUNDARY CONDITIONS		Base Paris	Case1 Paris	Case1ter Paris	Case1ter_HP	Case1bis Paris	Case2 Paris	Case2_HP	Case2bis Paris	Case2ter Paris	Case2ter_HP	Case3 Paris
Climate		Paris	Paris	Paris	Paris	Paris	Paris	Paris	Paris	Paris	Paris	Paris
Envelope performance		Low	Low	Low	Good	Good	Good	Good	Good	Good	Good	Excellent
Night time reduction		No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Thermostat on radiators		No	Yes	No	No	No	Yes	Yes	No	Yes	Yes	Yes
Split unit		Old	Old	New	New	Old	New	New	New	New	New	New
Boiler		Old	Old	New	Old	Old	New	No	New	New	Old	New
Heat Pump		No	No	No	Yes	No	No	Yes	No	No	Yes	No

RESULTS		Base Paris	Case1 Paris	Case1ter Paris	Case1ter_HP	Case1bis Paris	Case2 Paris	Case2_HP	Case2bis Paris	Case2ter Paris	Case2ter_HP	Case3 Paris
Energy demand												
Zone Heating demand	kWh/m²/y	290.9	205.5	254.9	254.9	69.6	47.4	47.4	62.3	47.4	47.4	7.8
Hot water demand	kWh/m²/y	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6
Cooling demand	kWh/m²/y	2.0	1.6	1.8	1.8	1.1	0.8	0.8	1.0	0.8	0.8	0.7
Electricity demand	kWh/m²/y	53.5	48.6	51.3	51.3	40.8	38.4	38.4	39.5	38.4	38.4	39.2
Total	**kWh/m²/y**	**359.0**	**268.4**	**320.6**	**320.6**	**124.2**	**99.3**	**99.3**	**115.3**	**99.3**	**99.3**	**60.3**
Final Energy Consumption												
Gas - Heating	kWhFE/m²/y	358.3	251.0	268.4	189.1	81.7	49.7	-	65.3	48.1	-	-
Gas - Domestic Hot Water	kWhFE/m²/y	15.6	15.4	13.3	9.4	14.8	13.2	-	13.2	12.8	11.2	18.5
Gas - Generation and supply losses	kWhFE/m²/y	45.5	46.8	10.0	22.6	47.5	7.3	-	7.2	10.1	27.0	7.3
Electricity - HP Heating	kWhFE/m²/y	-	-	-	31.6	-	-	17.5	-	-	17.5	-
Electricity - HP Domestic Hot Water	kWhFE/m²/y	-	-	-	-	-	-	5.2	-	-	-	-
Electricity - HP Generation Losses	kWhFE/m²/y	-	-	-	3.1	-	-	1.7	-	-	1.7	-
Electricity consumption - Auxiliaries EPBD	kWhFE/m²/y	36.0	31.0	33.4	33.4	23.0	20.3	20.3	21.4	20.3	20.3	21.1
Total	**kWhFE/m²/y**	**455.5**	**344.2**	**325.1**	**289.2**	**167.0**	**90.5**	**44.8**	**107.2**	**91.3**	**77.7**	**46.9**
Primary Energy Consumption												
Gas consumption	kWhPE/m²/y	419.4	313.3	291.7	221.0	144.0	70.1	-	85.8	71.0	38.1	25.7
Electricity consumption	kWhPE/m²/y	93.0	79.9	86.2	175.9	59.4	52.4	115.6	55.3	52.4	102.2	54.5
Total	**kWhPE/m²/y**	**512.4**	**393.2**	**377.9**	**396.9**	**203.4**	**122.5**	**115.6**	**141.0**	**123.4**	**140.3**	**80.2**
CO2 Emissions												
Gas emissions	kgCO2eq/m²/y	101.9	76.1	70.9	53.7	35.0	17.0	-	20.8	17.3	9.3	6.3
Electricity emissions	kgCO2eq/m²/y	7.6	6.6	7.1	14.4	4.9	4.3	9.5	4.5	4.3	8.4	4.5
Total	**kgCO2eq/m²/y**	**109.5**	**82.7**	**77.9**	**68.1**	**39.9**	**21.3**	**9.5**	**25.4**	**21.5**	**17.6**	**10.7**

Primary Energy Factor France (source:Arrêté du 26 octobre 2010)

Evlectricity	2.58
Natural Gas	1.00

CO2 emission factor France (source: Ademe)

Electricity	82 kgCO2eq/kWh
Natural Gas	243 kgCO2eq/kWh

It is important to notice that the category Electricity consumption Auxiliaries EPBD refers only to the consumptions defined in this European standard.

For each of these variants, there are in addition 18.2 kWh/yr/m² not mentioned in this summary, that are brought to the building by internal gains beyond the normative frame (domestic equipment). Those gains are positive to the thermal balance in winter, but are not taken in consideration by the EPBD guidelines. They are nonetheless presented in the variants comparisons below.

1. **Paris Comparison - Energy**

1.2. Results Summary (total)

BOUNDARY CONDITIONS		Base Paris	Case1 Paris	Case1ter Paris	Case1ter_HP	Case1bis Paris	Case2 Paris	Case2_HP	Case2bis Paris	Case2ter Paris	Case2ter_HP	Case3 Paris
Climate		Paris	Paris	Paris	Paris	Paris	Paris	Paris	Paris	Paris	Paris	Paris
Envelope performance		Low	Low	Low	Good	Good	Good	Good	Good	Good	Good	Excellent
Night time reduction		No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Thermostat on radiators		No	Yes	No	No	No	Yes	Yes	No	Yes	Yes	Yes
Split unit		Old	Old	New	New	Old	New	New	New	New	New	New
Boiler		Old	Old	New	Old	Old	New	No	New	New	Old	New
Heat Pump		No	No	No	Yes	No	No	Yes	No	No	Yes	No

RESULTS		Base Paris	Case1 Paris	Case1ter Paris	Case1ter_HP	Case1bis Paris	Case2 Paris	Case2_HP	Case2bis Paris	Case2ter Paris	Case2ter_HP	Case3 Paris
Energy demand												
Zone Heating demand	MWh/y	306	217	269	269	73	50	50	66	50	50	8
Hot water demand	MWh/y	13	13	13	13	13	13	13	13	13	13	13
Cooling demand	MWh/y	2	2	2	2	1	1	1	1	1	1	1
Electricity demand	MWh/y	56	51	54	54	43	40	40	42	40	40	41
Total	**MWh/y**	**378**	**283**	**338**	**338**	**131**	**105**	**105**	**122**	**105**	**105**	**64**
Final Energy Consumption												
Gas - Heating	MWhFE/y	378	264	283	199	86	52	-	69	51	-	-
Gas - Domestic Hot Water	MWhFE/y	16	16	14	10	16	14	-	14	14	12	19
Gas - Generation and supply losses	MWhFE/y	48	49	11	24	50	8	-	8	11	28	8
Electricity - Heating	MWhFE/y	-	-	-	33	-	-	18	-	-	18	-
Electricity - Domestic Hot Water	MWhFE/y	-	-	-	-	-	-	5	-	-	-	-
Electricity - Generation Losses	MWhFE/y	-	-	-	3	-	-	2	-	-	2	-
Electricity consumption - Auxiliaries EPBD	MWhFE/y	38	33	35	35	24	21	21	23	21	21	22
Total	**MWhFE/y**	**480**	**363**	**343**	**305**	**176**	**95**	**47**	**113**	**96**	**82**	**49**
Primary Energy Consumption												
Gas consumption	MWhPE/y	442	330	307	233	152	74	-	90	75	40	27
Electricity consumption	MWhPE/y	98	84	91	185	63	55	122	58	55	108	57
Total	**MWhPE/y**	**540**	**414**	**398**	**418**	**214**	**129**	**122**	**149**	**130**	**148**	**85**
CO2 Emissions												
Gas emissions	tCO2eq/y	107	80	75	57	37	18	-	22	18	10	7
Electricity emissions	tCO2eq/y	8	7	7	15	5	5	10	5	5	9	5
Total	**tCO2eq/y**	**115**	**87**	**82**	**72**	**42**	**22**	**10**	**27**	**23**	**19**	**11**

Primary Energy Factor France (source:Arrêté du 26 octobre 2010)

Evlectricity 2.58

Natural Gas 1.00

CO2 emission factor France (source: Ademe)

Electricity 82 kgCO2eq/kWh

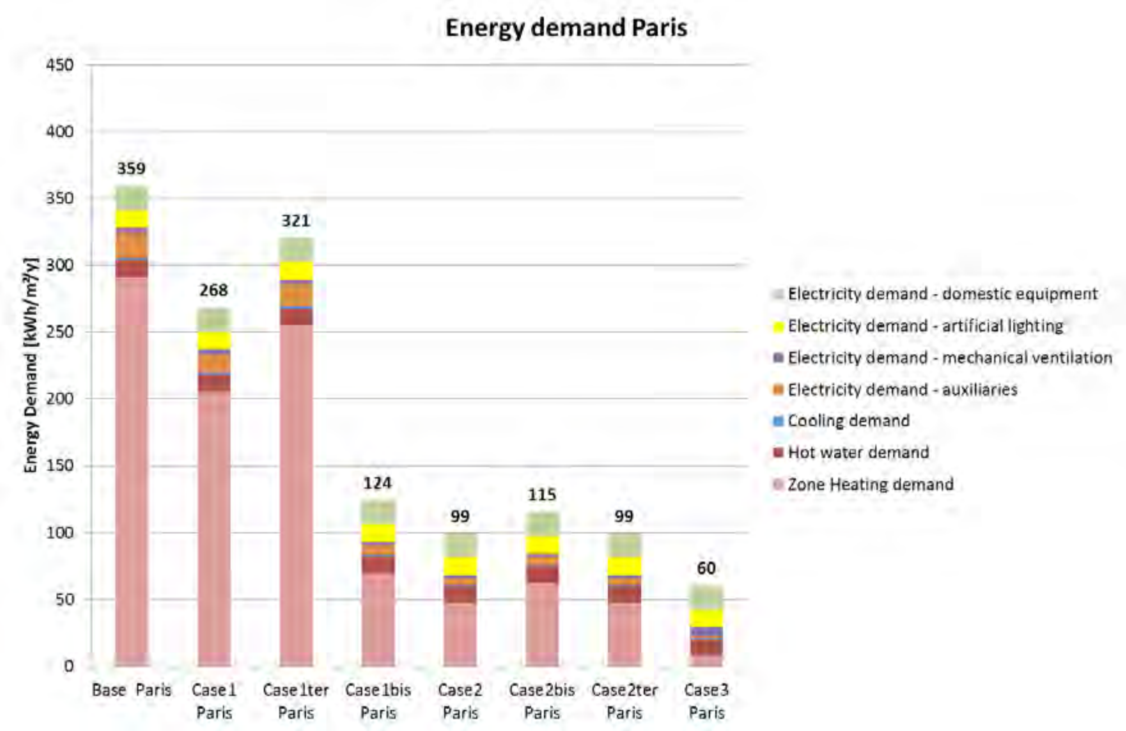
Natural Gas 243 kgCO2eq/kWh

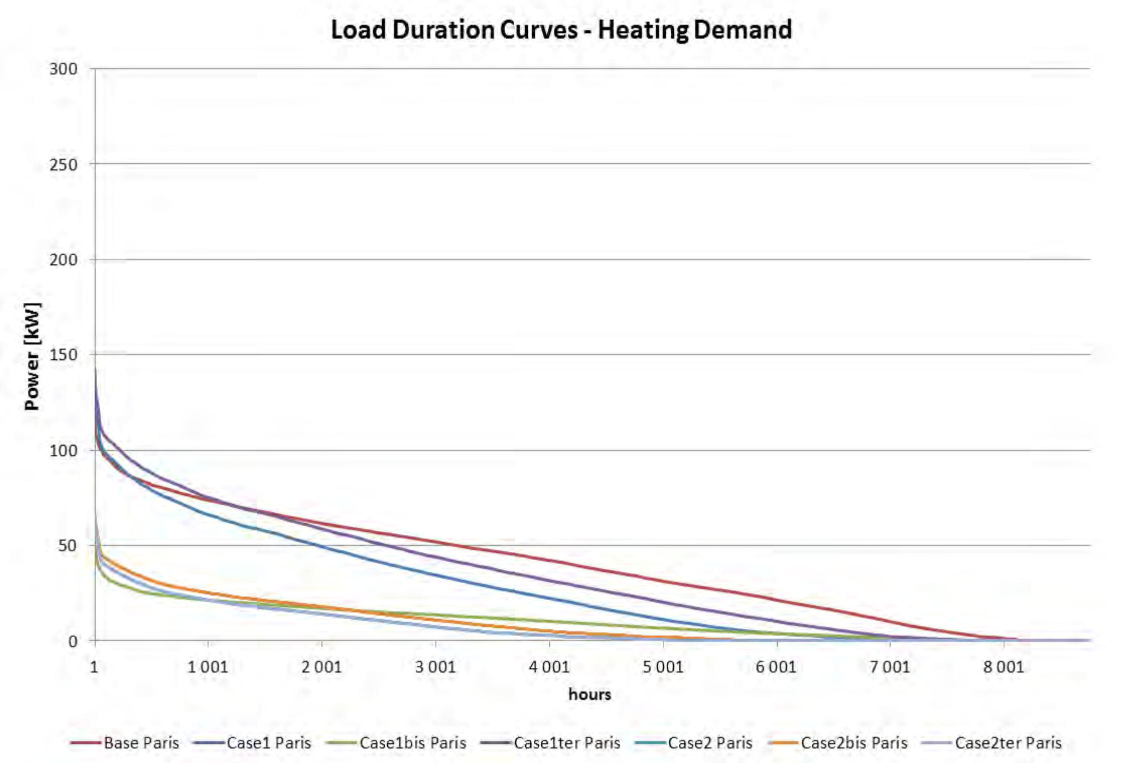
It is important to notice that the category Electricity consumption Auxiliaries EPBD refers only to the consumptions defined in this European standard.

For each of these variants, there are in addition 19.2 MWh/yr not mentioned in this summary, that are brought to the building by internal gains beyond the normative frame (domestic equipment). Those gains are positive to the thermal balance in winter, but are not taken in consideration by the EPBD guidelines. They are nonetheless presented in the variants comparisons below.

1.3. Energy Demand

The following results compare different envelope, control and system variants for the Parisian climate.





LEGEND

Base: Low Envelope Performance, No Control, Old Boiler, Low efficiency split unit. Plant dimensioned on the low envelope demand.

Case 1: Low Envelope Performance, Nighttime Reduction, Thermostat on radiators, Old Boiler, Low efficiency split unit. Plant dimensioned on the low envelope demand.

Case 1bis: Good Envelope Performance, No Control, Old Boiler, low efficiency split unit. Plant dimensioned on the low envelope demand.

Case 1ter: Low Envelope Performance, Nighttime Reduction, New Boiler, High efficiency split unit. Plant dimensioned on the low envelope demand.

Case 2: Good Envelope Performance, Nighttime Reduction, Thermostat on Radiators, New Boiler. High efficiency split unit. Plant dimensioned on good envelope demand.

Case 2bis:Good Envelope Performance, Nighttime Reduction, New Boiler, High efficiency split unit. Plant dimensioned on the good envelope.

Case 2ter:Good Envelope Performance, Nighttime Reduction, Thermostat on Radiators, New Boiler, High efficiency split unit. Plant dimensioned on the low envelope.

Case 3:Excellent Envelope Performance, Nighttime Reduction, Thermostat on Radiators, New Boiler, High efficiency split unit. Plant dimensioned on the excellent envelope.

Comments

Increasing envelope performance from Base performance level to Good performance level reduces heating demand by 76% (-221 kWh/m²/y) while reducing at the same time heating peak loads (-59% heating peak load, 70kW reduction). Thanks to a better protection against solar gains, this improved envelope also reduces cooling energy demand (-44%, -0.9 kWh/m²/h) and peak cooling power (-50%, -11.1 kW).

Night time reduction consists in reducing the heating temperature set point during nighttime in order to save energy when we sleep. It has several consequences on heating demand:

- It reduces heating energy demand by 12% (-35 kWh/m²/y) thanks to the temperature set point decrease (-5°C) during night time.
- But it also increases heating peak loads by +18% (+22 kW) due to additional power needed to increase the room temperature each morning from the night time temperature set point, to the daytime temperature set point (5°C difference). This morning reheat overload has already been mitigated by using a set point ramp progressively increasing the temperature between 6AM and 7AM.

Combined with night time reduction, implementing thermostats on radiators has a positive impact on heating demand:

- Compared to the base case with the same level of envelope, it reduces heating energy demand by 29% (-85 kWh/m²/y),
- Compared to the base case with the same level of envelope, there is still an increase for the total heating peak power (+12%, +14 kW), but it is reduced in comparison with the variant where only the night time reduction has been implemented.

The best studied variant with an Excellent envelope and new control strategies show a heating energy demand reduction of -97% (-283 kWh/m²/y) and a peak heating power reduction of -73% (-88 kW). In this situation, heating is no longer the most important source of energy demand.

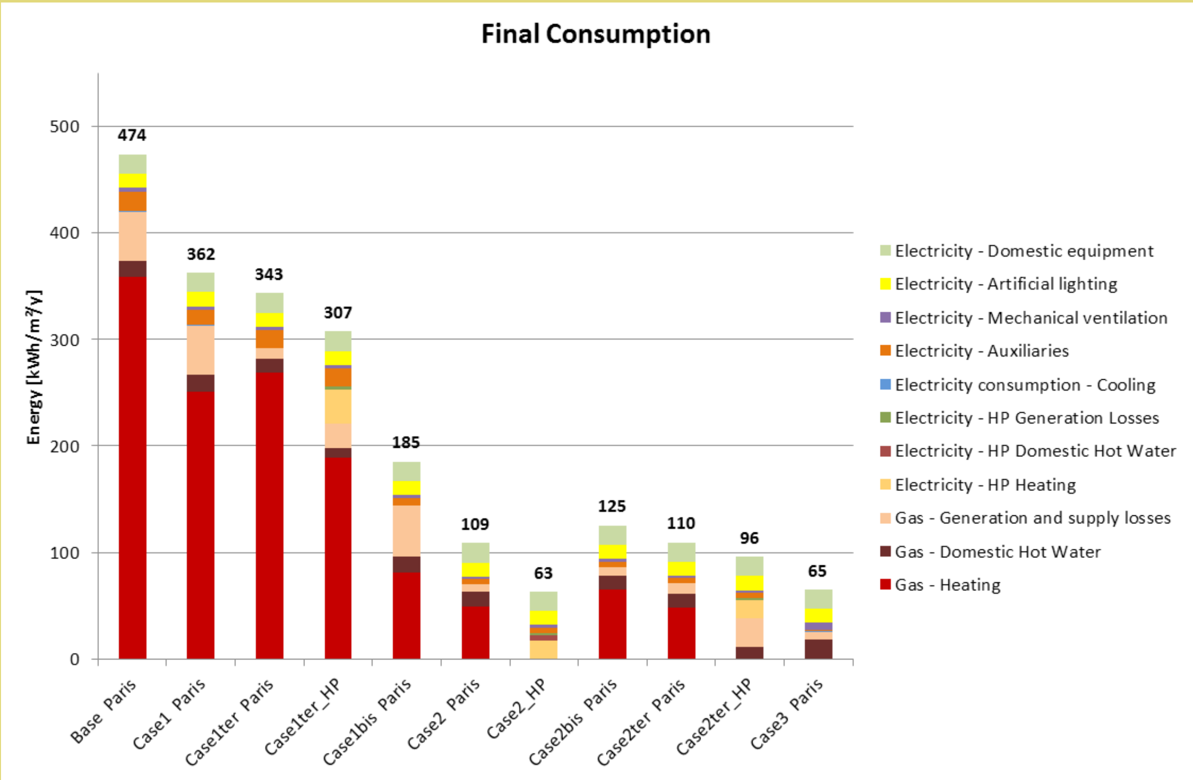
NB: It is important to notice that electrical demand for domestic equipment is limited (18.2 kWh/m².y) which translates an eco-friendly behavior from the building occupants. As a consequence, heating demand is slightly increased. This domestic equipment is not taken into account in the summary tables, because it is not tackled by EPBD directives. It is coherent to show these gains here because they have a positive role in heating demand reduction in winter.

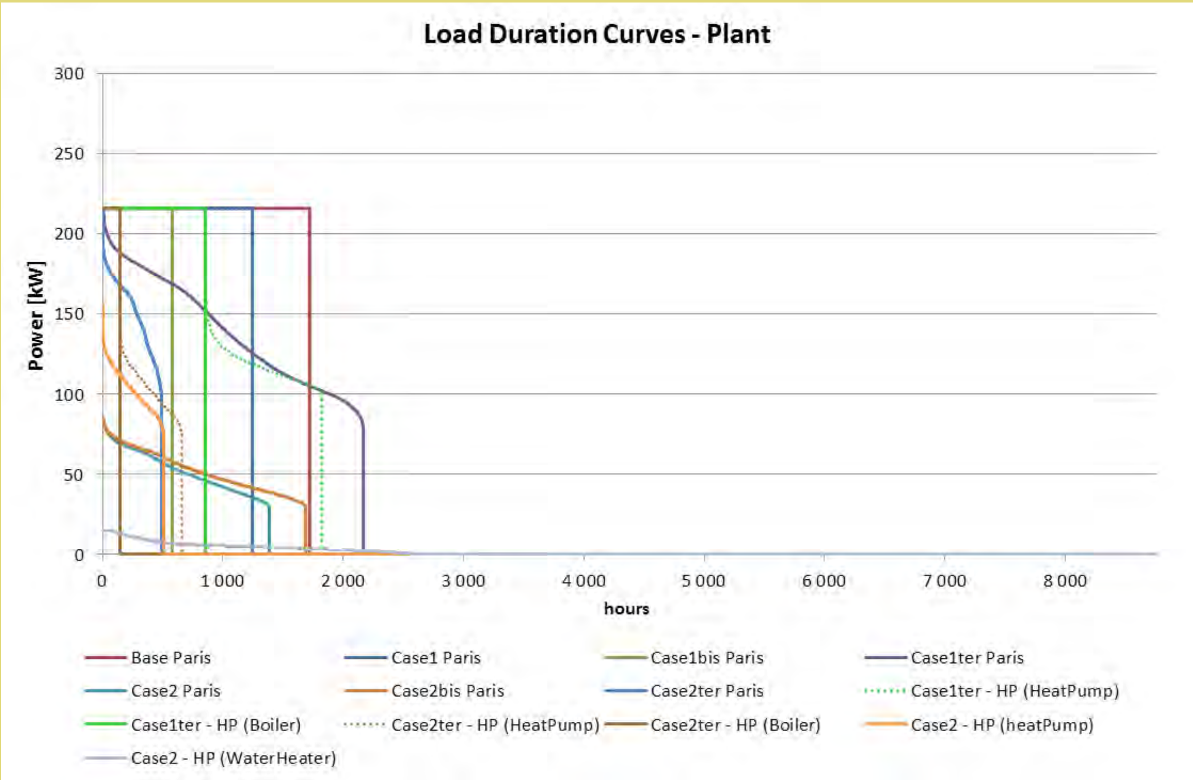
1. **Paris Comparison - Energy**

1.4. Final Energy Consumption

sized acc. to good envelope performance — sized acc. to low envelope performance

BOUNDARY CONDITIONS	Base Paris	Case1 Paris	Case1ter Paris	Case1ter_HP	Case1bis Paris	Case2 Paris	Case2_HP	Case2bis Paris	Case2ter Paris	Case2ter_HP	Case3 Paris
Climate	Paris	Paris	Paris	Paris	Paris	Paris	Paris	Paris	Paris	Paris	Paris
Envelope performance	Low	Low	Low	Good	Good	Good	Good	Good	Good	Good	Excellent
Night time reduction	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Thermostat on radiators	No	Yes	No	No	No	Yes	Yes	No	Yes	Yes	Yes
Split unit	Old	Old	New	New	Old	New	New	New	New	New	New
Boiler	Old	Old	New	Old	Old	New	No	New	New	Old	New
Heat Pump	No	No	No	Yes	No	No	Yes	No	No	Yes	No





Comments

Refurbishing the boiler equipment and increasing its overall efficiency translates into a gas consumption reduction of -30% (-127 kWh/m²/y) for the same poorly insulated envelope. This improvement is due to different factors:

- The new condensing boiler operates at a higher efficiency by limiting the heat losses during heat generation
- Due to the modulating burner, the gas boiler adapts its power according to the demand, which translates into a higher heat generation efficiency
- As the boiler room has been refurbished, the piping distribution has been well insulated, which reduces supply losses

As a well-insulated building (envelope performance = Good) tends to have lower energy demand for space heating, the generation and supply heat losses represent a higher portion of the total gas consumption if the boiler equipment has not been refurbished. As a consequence, improving the boiler equipment in a well-insulated building translates into a gas consumption reduction of -40% (-58 kWh/m²/y).

Using an oversized new boiler with a modulating burner (very high efficiency boiler) increases only by 1% the total gas consumption compared to a correctly sized one. This is due to the new modulating burner capacity of limiting its functioning to 10% of its nominal power. But if the building envelope has been first refurbished to a Good level, the new boiler sizing can be reduced by 61% (-132 kW). This difference can be translated into:

- investment cost savings
- maintenance costs savings
- grey energy savings

Once the envelope has been refurbished, domestic hot water and plant generation and distribution losses are representing a significant part of the gas bill (up to 43% of the total gas consumption with a Good envelope).

Installing a heat pump to replace the old boiler achieves the lowest final energy demand thanks to an efficient seasonal coefficient of performance (2.8). But to benefit from all the heat pump potential, the envelope has to be well-insulated. Otherwise, using a heat pump with a unrefurbished envelope requires to keep an existing boiler to handle high temperature regimes with low outside air temperature (cf chapter 1.8).

Also, as heat pumps are supplied by electricity, the gain in final energy (compared to a new boiler variant) is reduced when looking at the primary energy numbers (cf summary tables).

NB: The boiler has been sized according to standard sizing methods using a "worst case scenario" approach. For instance, no heat gains and the most critical outside air temperature is considered to calculate the peak heating load with a 20% safety coefficient. This explains the difference in the "Base" case between the boiler peak power design sizing, and the peak heating demand calculated via thermal modeling.

NB: It is important to notice that electrical demand for domestic equipment is limited (18.2 kWh/m².y) which translates an eco-friendly behavior from the building occupants. As a consequence, heating demand is slightly increased. This domestic equipment is not taken into account in the summary tables, because it is not tackled by EPBD directives. It is coherent to show these gains here because they have a positive role in heating demand reduction in winter.

STEP 0. BASE

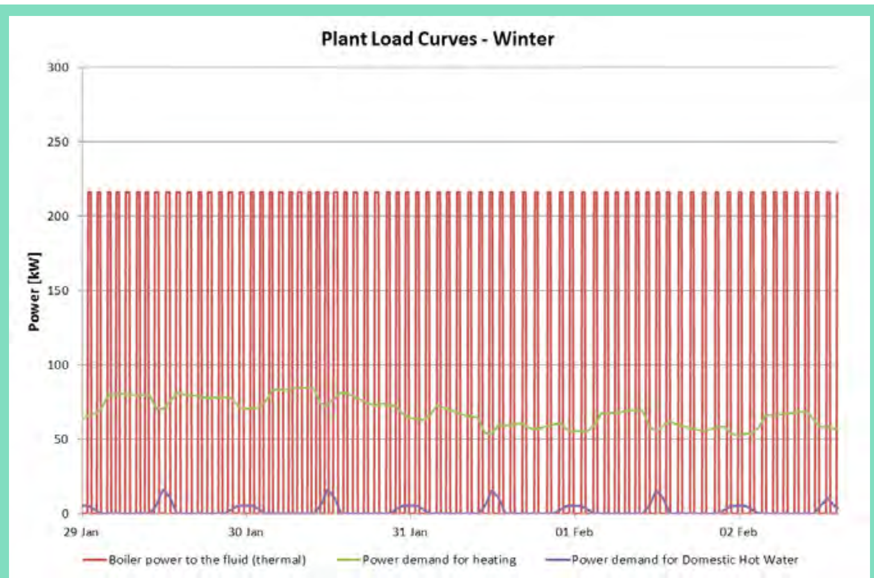
Base Case: Low Envelope Performance, Old Boiler, No Control

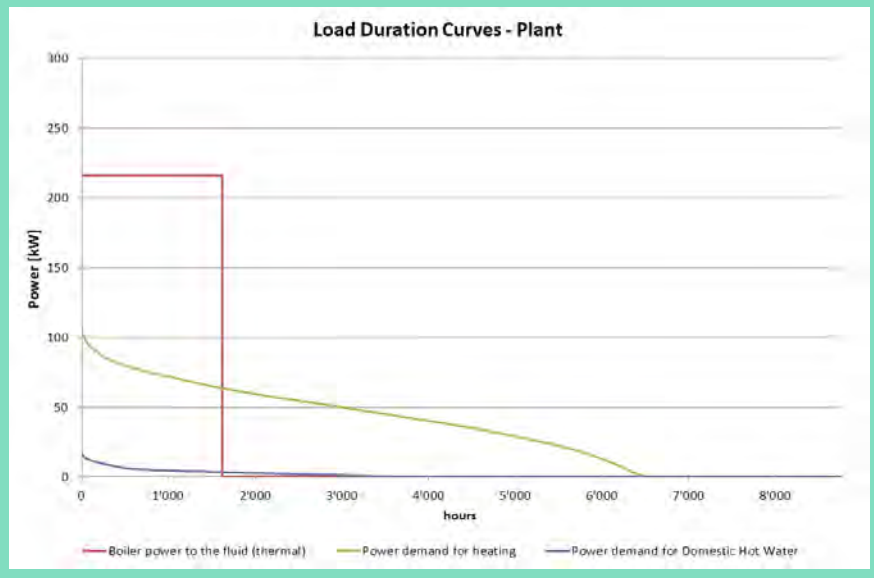
The old boiler is oversized compared to the real power demand (+80%), as it is common in existing buildings. The piping is not well-insulated.

As it is equipped with a single-speed burner, it can only function at nominal power. As a consequence, it is functioning by short repeated ON/OFF cycles where the boiler, starts, then heats up the buffer tank, stops when the buffer tank is hot enough, and wait until the buffer storage has delivered its heat to the distribution loops.

This phenomenon induces numerous starts and stops for the boiler, which reduces its life expectancy.

Moreover, each time the boiler stops and starts again, heat is lost while the boiler is cooling, and heat is wasted while the boiler is starting again.





- Stand-by + firing losses: 22.0 kWh/m²/y
- Distribution losses: 15.0 kWh/m²/y
- Peak heating + DHW demand: 120 kW
- Boiler Thermal Peak power: 216 kW

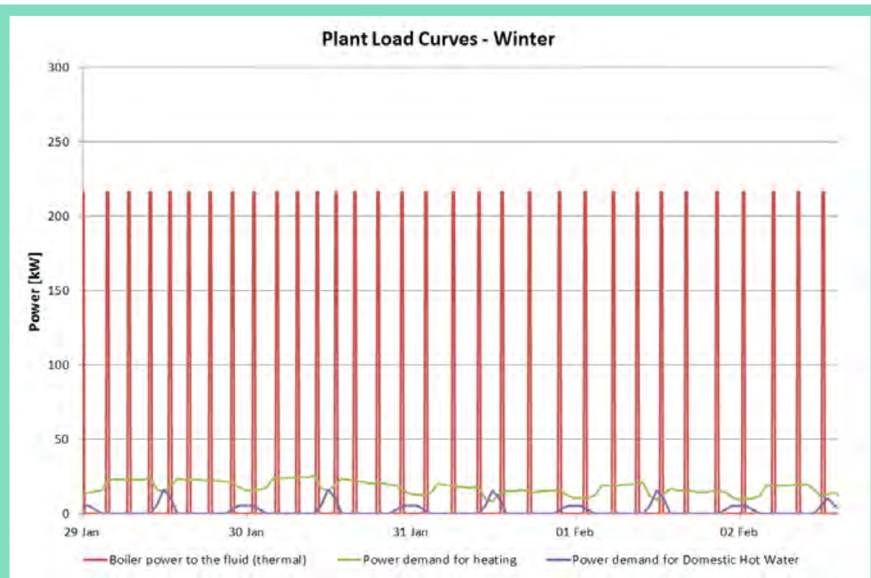
STEP 1. ENVELOPE REFURBISHMENT

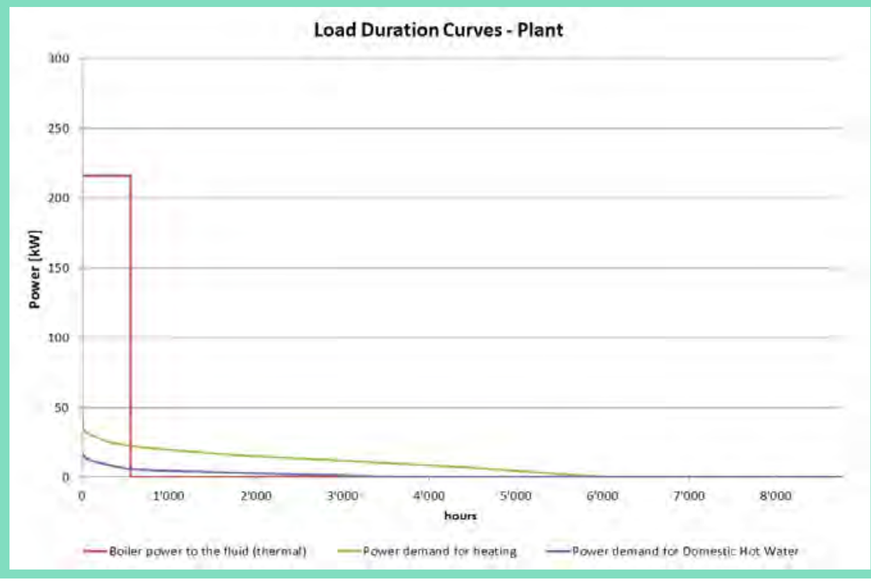
Case 1bis: **Good Envelope Performance**, Old Boiler, No Control, Plant dimensioned on the Low Envelope Demand

The envelope has been refurbished. As a consequence, the heating peak power and energy demands have been reduced.

Hence, the single-speed burner is functioning less frequently, but always by short ON/OFF cycles.

Stand-by and firing losses have increased (+3.2 kWh/m²/y) as the boiler is functioning less frequently while still losing heat in its environment.





- Stand-by + firing losses: 25.2 kWh/m²/y
- Distribution losses: 15.3 kWh/m²/y
- Peak heating + DHW demand: 50 kW
- Boiler Thermal Peak power: 216 kW

STEP 2. PLANT REFURBISHMENT, CONTROL SYSTEMS

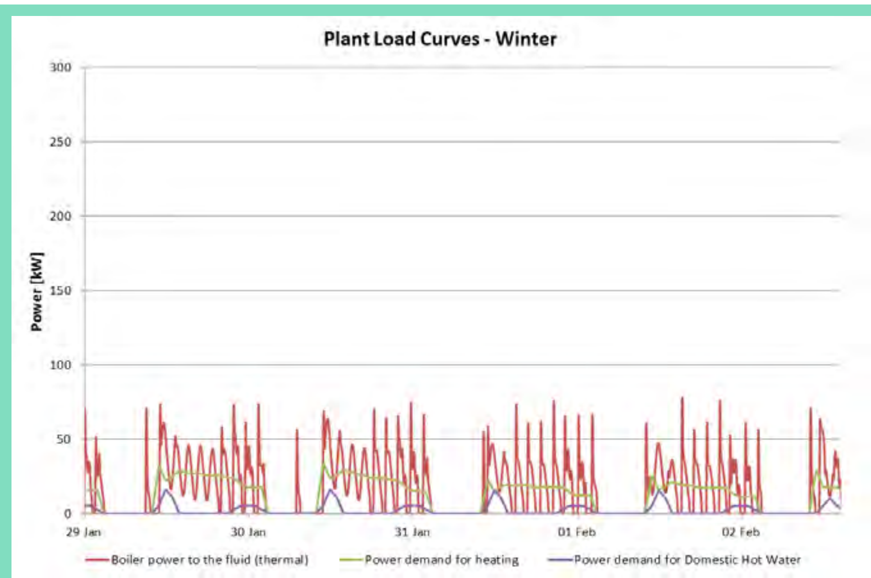
Case 2: Good Envelope Performance, **New Boiler**, **Nighttime Reduction, Thermostat on Radiators**. Plant dimensioned on the Good Envelope Demand

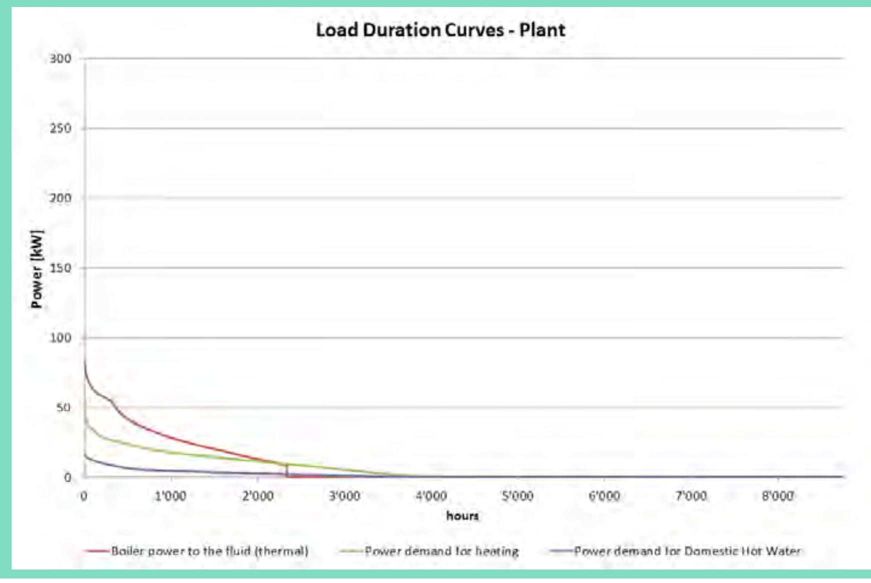
The old boiler has been replaced with a condensing boiler and the boiler equipment has been refurbished and insulated. Nighttime reduction and thermostats on radiators have been implemented.

Distribution losses have been reduced (-8.6 kWh/m²/y, -57%) thanks to the plant equipment (pipes, boiler) thermal insulation.

Stand-by and firing losses have been reduced (-21.5 kWh/m²/y, more than 95% reduction). The new boiler loses less heat in its environment, and as it modulates its power, reduces its firing losses.

The boiler is better sized to the heating and domestic hot water demand. With its speed-modulating burner, it adapts its power to the right demand. As a consequence, the boiler does not function with ON/OFF cycles anymore, which should increase its durability.





- Stand-by + firing losses: 0.5 kWh/m²/y
- Distribution losses: 6.4 kWh/m²/y
- Peak heating + DHW demand: 64 kW
- Boiler Thermal Peak power: 84 kW

STEP 0. BASE

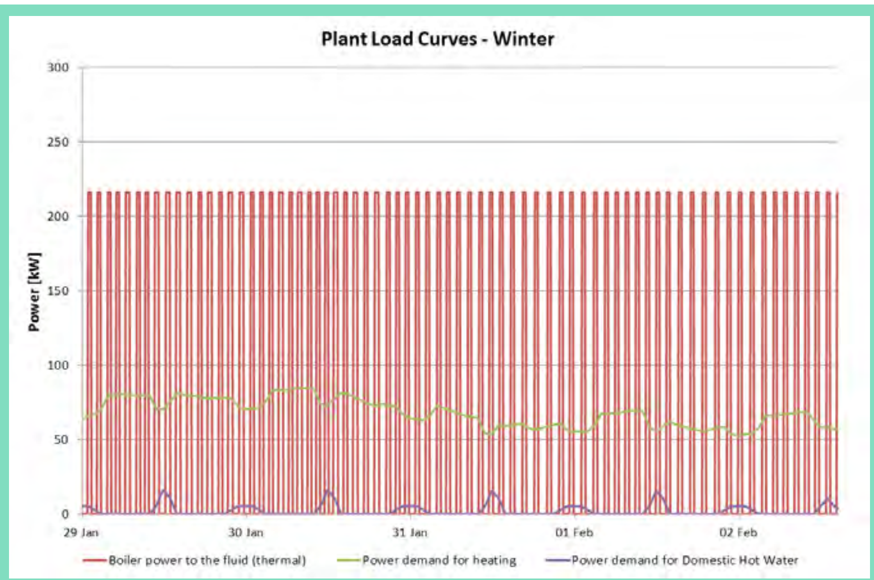
Base Case: Low Envelope Performance, Old Boiler, No Control

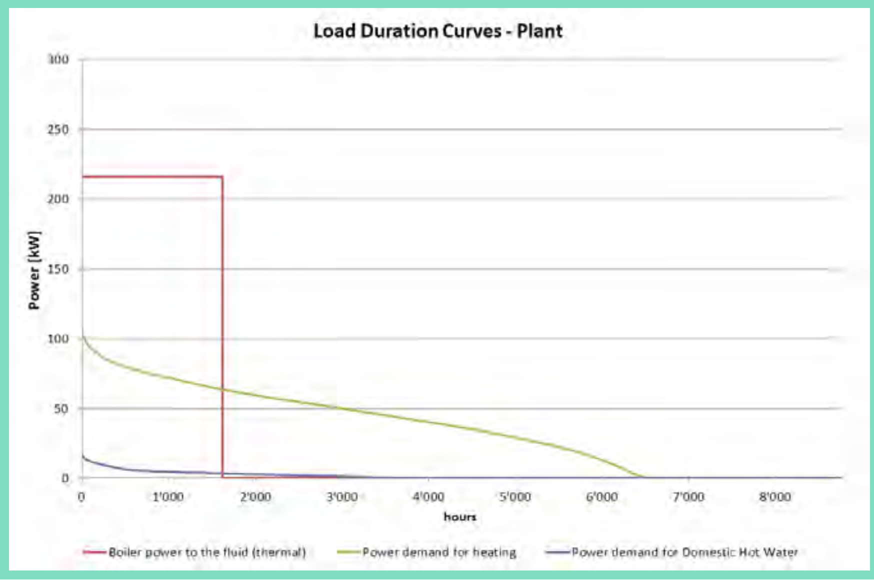
The old boiler is oversized compared to the real power demand (+80%), as it is common in existing buildings. The piping is not well-insulated.

As it is equipped with a single-speed burner, it can only function at nominal power. As a consequence, it is functioning by short repeated ON/OFF cycles where the boiler, starts, then heats up the buffer tank, stops when the buffer tank is hot enough, and wait until the buffer storage has delivered its heat to the distribution loops.

This phenomenon induces numerous starts and stops for the boiler, which reduces its life expectancy.

Moreover, each time the boiler stops and starts again, heat is lost while the boiler is cooling, and heat is wasted while the boiler is starting again.





- Stand-by + firing losses: 22.0 kWh/m²/y
- Distribution losses: 15.0 kWh/m²/y
- Peak heating + DHW demand: 120 kW
- Boiler Thermal Peak power: 216 kW

STEP 1. PLANT REFURBISHMENT, CONTROL SYSTEM

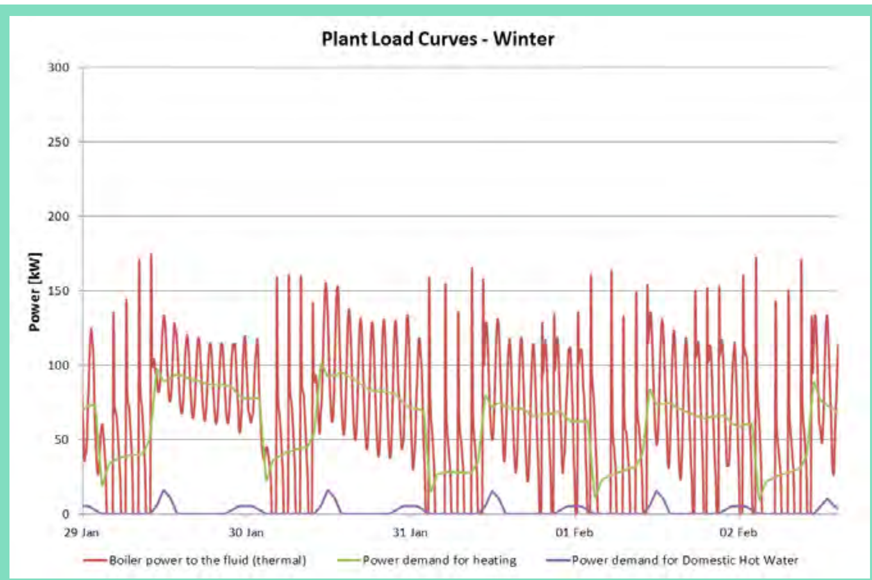
Case 1ter: Low Envelope Performance, **New Boiler, Nighttime Reduction**, Plant dimensioned on the Low Envelope Demand

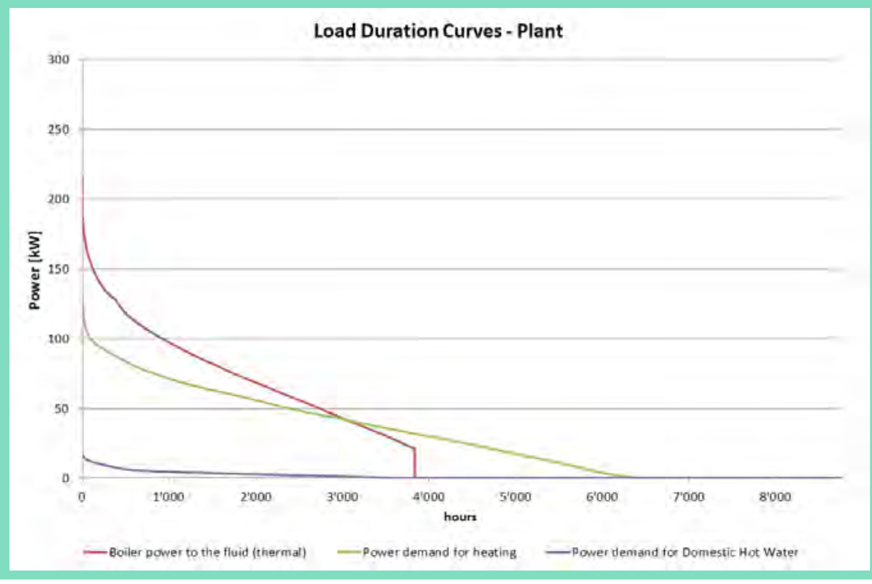
The old boiler has been replaced with a condensing boiler and the plant equipment has been refurbished and reinsulated. Nighttime reduction has been implemented

As the envelope stays the same, the boiler has the same peak load as before. But with its speed-modulating burner, it adapts its power to the right demand. As a consequence, the boiler does not function as much as before with ON/OFF cycles, which should increase its durability.

Stand-by and firing losses have been greatly reduced (-21 kWh/m²/y, more than 95% reduction). The new boiler loses less heat in its environment, and as it modulates its power, reduces its firing losses.

Distribution losses have also been greatly reduced (-6.5 kWh/m²/y, -43%) thanks to the plant equipment (pipes, boiler) thermal insulation.





- Stand-by + firing losses: 1.0 kWh/m²/y
- Distribution losses: 8.5 kWh/m²/y
- Peak heating + DHW demand: 142 kW
- Boiler Thermal Peak power: 216 kW

STEP 2. ENVELOPE REFURBISHMENT, CONTROL SYSTEM

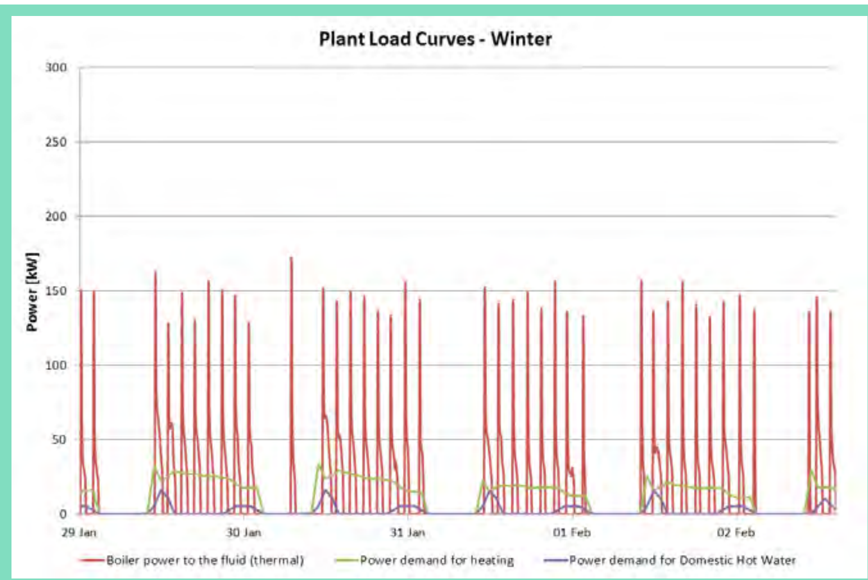
Case 2ter: **Good Envelope Performance,** New Boiler, Nighttime Reduction, **Thermostat on Radiators**. Plant dimensioned on the low Envelope Demand

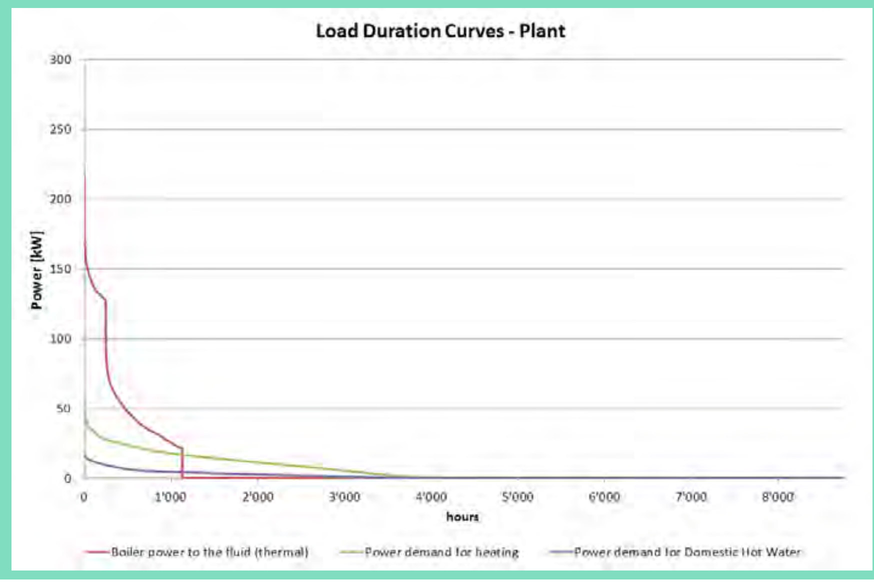
The envelope has been refurbished and thermostats have been implemented on radiators, reducing the heating peak power and energy demands.

As a consequence, the new boiler is strongly oversized and the variable-speed burner is functioning less frequently, with shorter cycles.

Stand-by and firing losses have slightly increased (+0.6 kWh/m²/y) as the boiler is functioning less frequently while still losing heat in its environment.

With this “Boiler First” refurbishment strategy, as the plant equipment is generally oversized and despite being well-insulated, its generation and distribution losses are 45% higher (3.1 kWh/m²/y) than after the “Envelope First” refurbishment strategy





- Stand-by + firing losses: 1.6 kWh/m²/y
- Distribution losses: 8.4 kWh/m²/y
- Peak heating + DHW demand: 64 kW
- Boiler Peak power: 84 kW

STEP 0. BASE

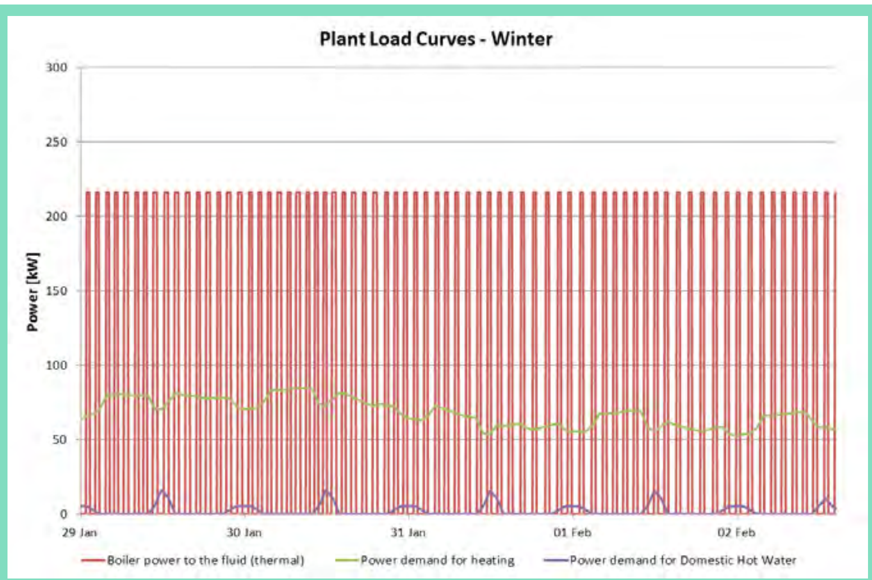
Base Case: Low Envelope Performance, Old Boiler, No Control

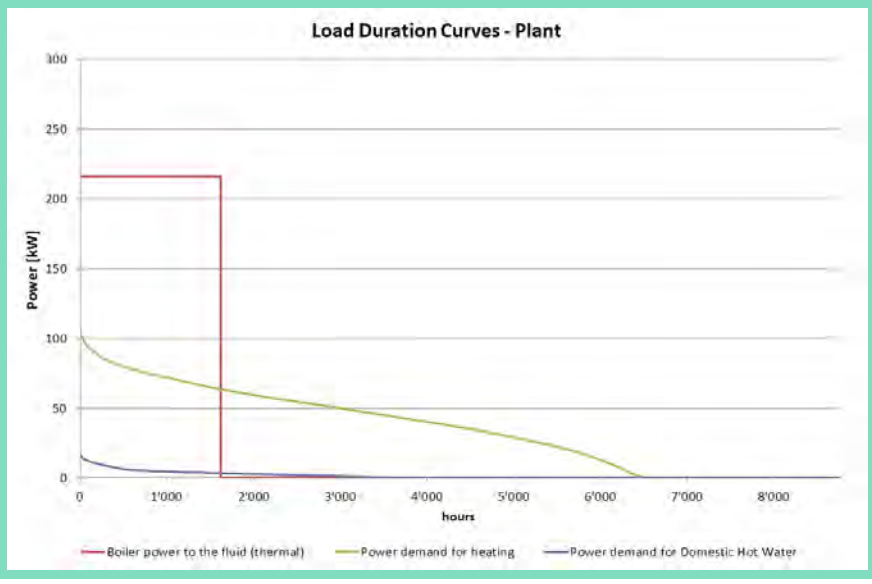
The old boiler is oversized compared to the real power demand (+80%), as it is common in existing buildings. The piping is not well-insulated.

As it is equipped with a single-speed burner, it can only function at nominal power. As a consequence, it is functioning by short repeated ON/OFF cycles where the boiler, starts, then heats up the buffer tank, stops when the buffer tank is hot enough, and wait until the buffer storage has delivered its heat to the distribution loops.

This phenomenon induces numerous starts and stops for the boiler, which reduces its life expectancy.

Moreover, each time the boiler stops and starts again, heat is lost while the boiler is cooling, and heat is wasted while the boiler is starting again.





- Stand-by + firing losses: 22.0 kWh/m²/y
- Distribution losses: 15.0 kWh/m²/y
- Peak heating + DHW demand: 120 kW
- Boiler Thermal Peak power: 216 kW

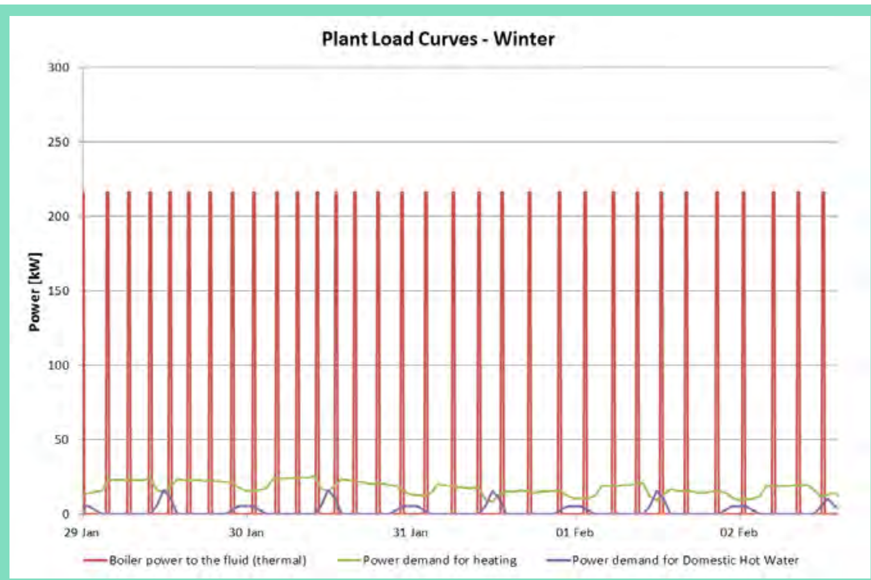
STEP 1. ENVELOPE REFURBISHMENT

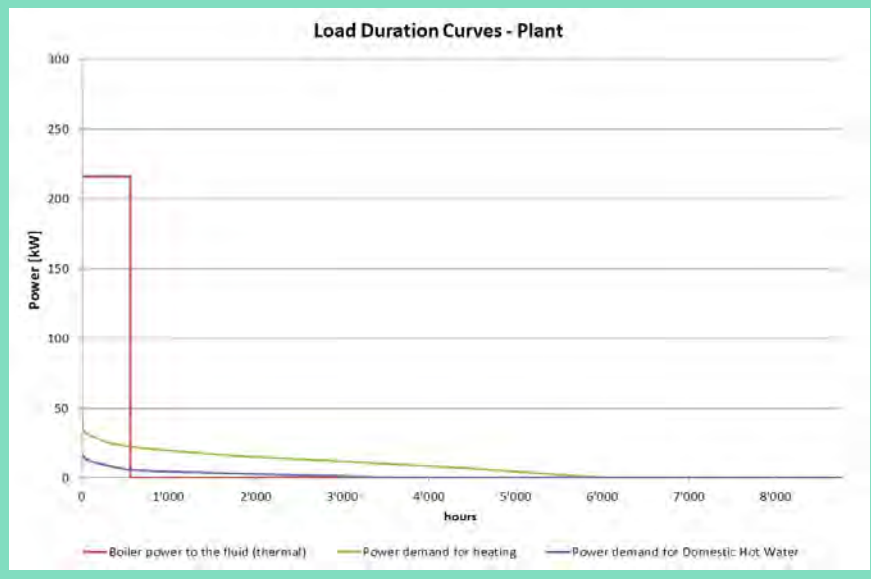
Case 1bis: **Good Envelope Performance**, Old Boiler, No Control, Plant dimensioned on the Low Envelope Demand

The envelope has been refurbished. As a consequence, the heating peak power and energy demands have been reduced.

Hence, the single-speed burner is functioning less frequently, but always by short ON/OFF cycles.

Stand-by and firing losses have incvreased (+3.2 kWh/m²/y) as the boiler is functioning less frequently while still losing heat in its environment.





- Stand-by + firing losses: 25.2 kWh/m²/y
- Distribution losses: 15.3 kWh/m²/y
- Peak heating + DHW demand: 50 kW
- Boiler Thermal Peak power: 216 kW

STEP 2. HEAT PUMP, CONTROL SYSTEMS

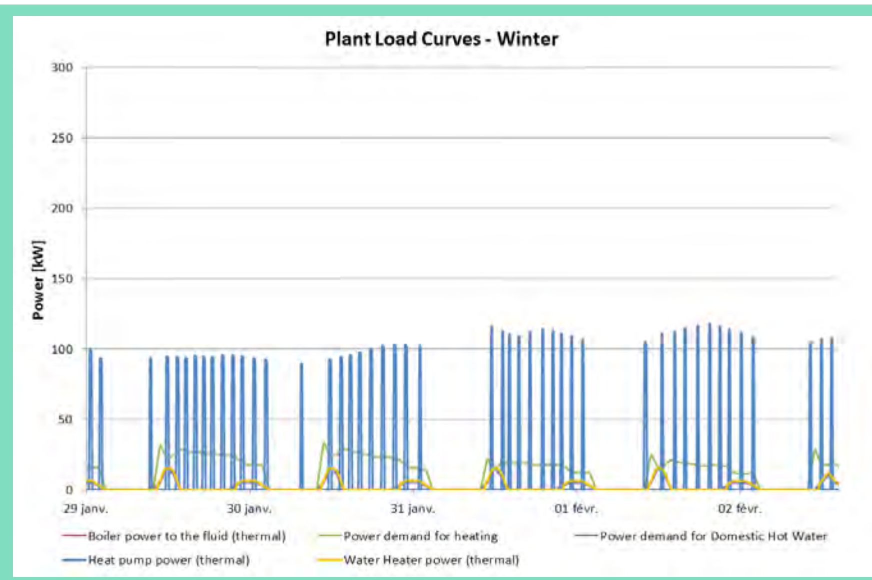
Case 2_HP: Good Envelope Performance, **New Heat Pump**, **Nighttime Reduction**, **Thermostat on Radiators**. Heat Pump dimensioned on the Good Envelope Demand

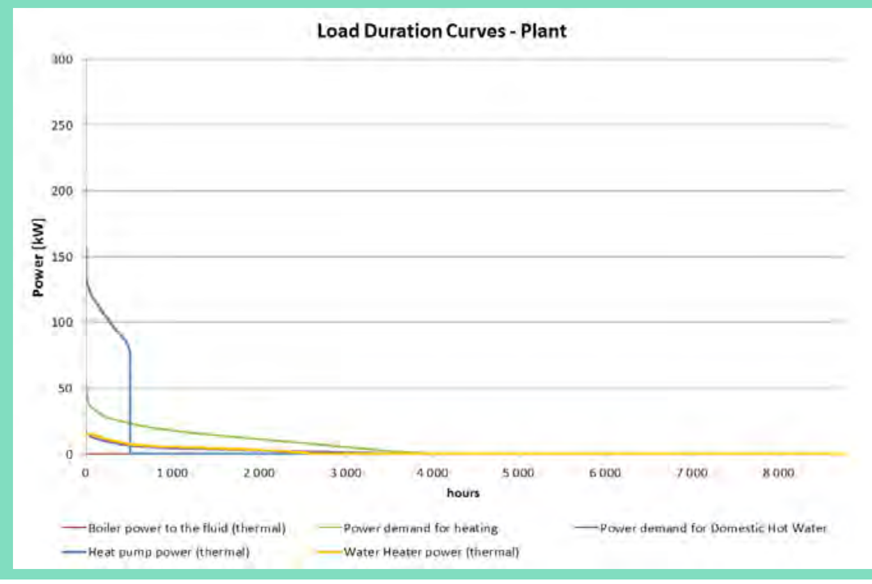
The old boiler has been replaced with two heat pumps and the hydraulics have been refurbished and insulated. Nighttime reduction and thermostats on radiators have been implemented. One heat pump is dedicated to heating, the other one to domestic hot water preparation.

The heat pumps are functionning efficiently, which results in elevated seasonal coefficient of performance (COP).

seasonal COP heating: 2.8

seasonal COP domestic hot water: 2.4





- Distribution losses: 3.3 kWh/m²/y
- Peak heating + DHW demand: 64 kW
- Heat Pump Thermal Peak power: 84 kW

STEP 0. BASE

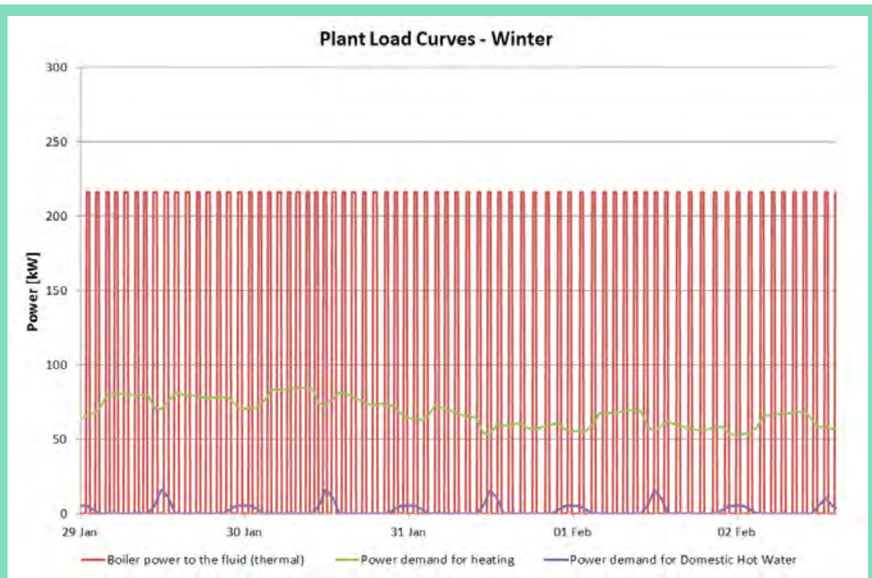
Base Case: Low Envelope Performance, Old Boiler, No Control

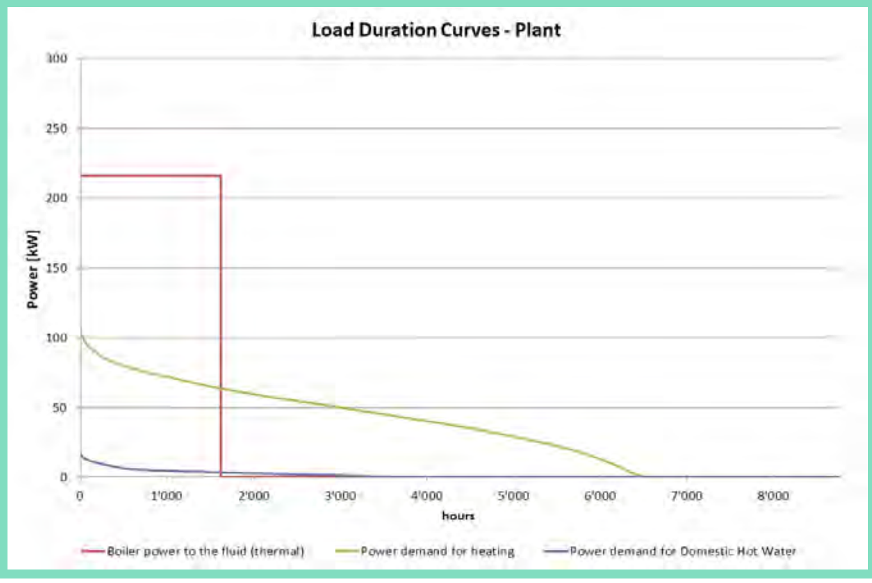
The old boiler is oversized compared to the real power demand (+80%), as it is common in existing buildings. The piping is not well-insulated.

As it is equipped with a single-speed burner, it can only function at nominal power. As a consequence, it is functioning by short repeated ON/OFF cycles where the boiler, starts, then heats up the buffer tank, stops when the buffer tank is hot enough, and wait until the buffer storage has delivered its heat to the distribution loops.

This phenomenon induces numerous starts and stops for the boiler, which reduces its life expectancy.

Moreover, each time the boiler stops and starts again, heat is lost while the boiler is cooling, and heat is wasted while the boiler is starting again.





- Stand-by + firing losses: 22.0 kWh/m²/y
- Distribution losses: 15.0 kWh/m²/y
- Peak heating + DHW demand: 120 kW
- Boiler Thermal Peak power: 216 kW

STEP 1. HEAT PUMP, CONTROL SYSTEM

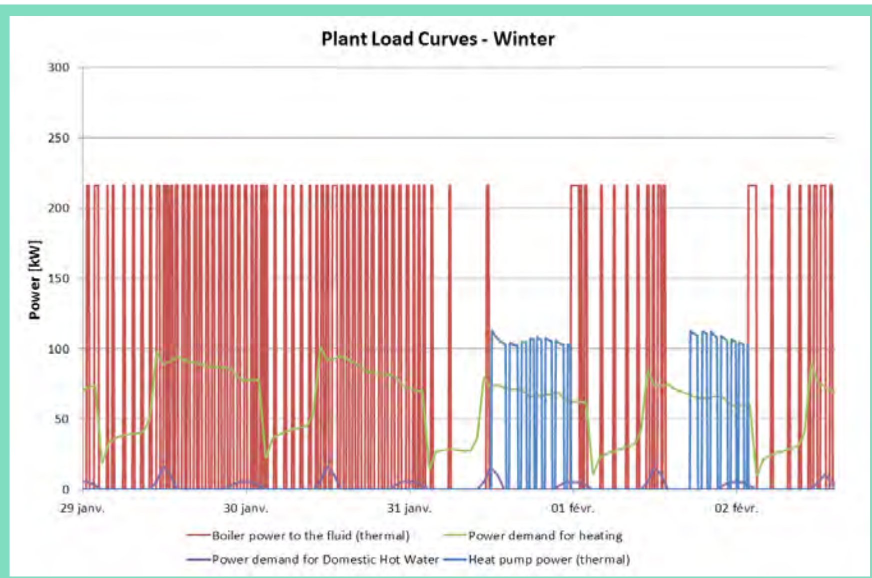
Case 1ter_HP: Low Envelope Performance, Old Boiler, **Heat Pump, Nighttime Reduction**, Plant dimensioned on the Low Envelope Demand

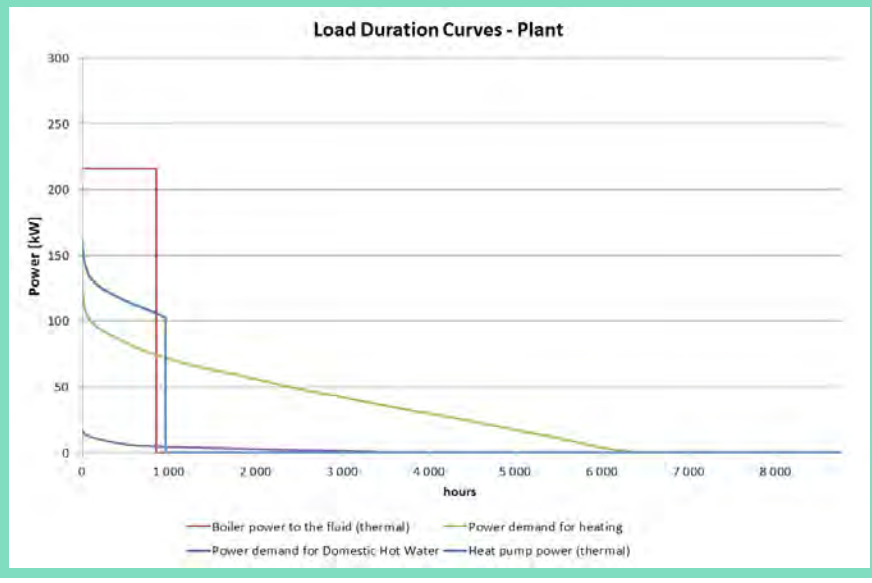
A heat pump has been added to cover the heating demand when outside air temperature is above 7°C, otherwise, heating is provided by the old boiler. The old boiler also covers the domestic hot water demand. The heat pump is running around 1000 hours.

This limitation is due to the temperature regime that has to be supplied to the radiators. With the old envelope, a high temperature regime is required in winter (80°C) which is not feasible for the selected heat pump. But in shoulder season, the radiator temperature regime can be reduced (lower than 55°C) and hence supplied by the new heat pump.

As the boiler supplies a major part of the heating demand, the overall efficiency is limited. But as the heat pump only functions when the outside air temperature is higher than 7°C, its seasonal coefficient of performance is higher than usual.

seasonal COP heating: 3.1 (only when T°C outside is above 7°C)





- Stand-by + firing losses: 22.6 kWh/m²/y
- Distribution losses: 6.1 kWh/m²/y
- Peak heating + DHW demand: 142 kW
- Heat Pump Thermal Peak power: 84 kW (sized for T°C outside = 7°C)

STEP 2. ENVELOPE REFURBISHMENT, CONTROL SYSTEM

Case 2ter_HP: **Good Envelope Performance,** New Boiler, Nighttime Reduction, **Thermostat on Radiators**. Plant dimensioned on the low Envelope Demand

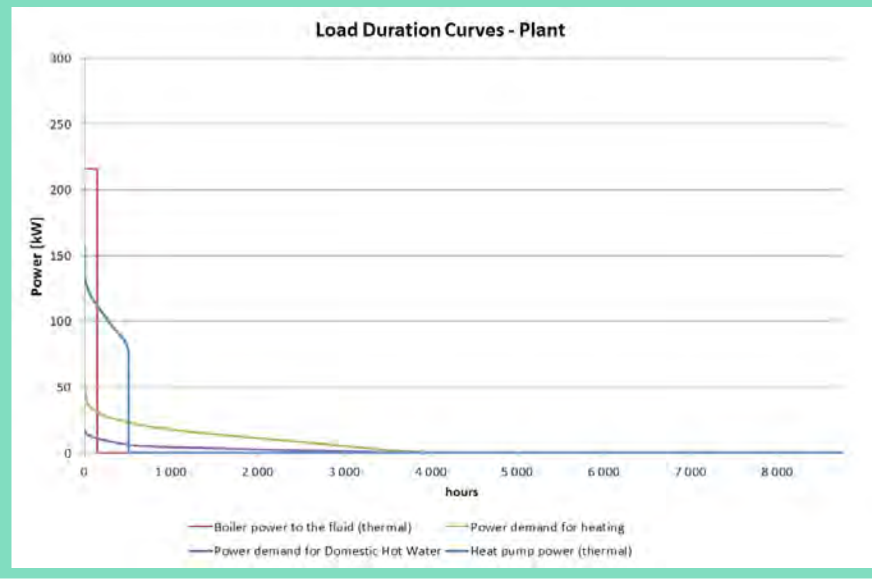
The envelope has been refurbished and thermostats have been implemented on radiators, reducing the heating peak power and energy demands.

As the heating demand has been reduced, the temperature regime in the radiators has been also reduced, which makes it possible to use the heat pump all year long.

As a consequence, the boiler is only used for domestic hot water preparation, while the heat pump covers all the heating demand.

The heat pump is functionning efficiently, which results in an elevated seasonal coefficient of performance (COP), while the old boiler generates important stand by and firing losses due to its low performance.

seasonal COP heating: 2.8

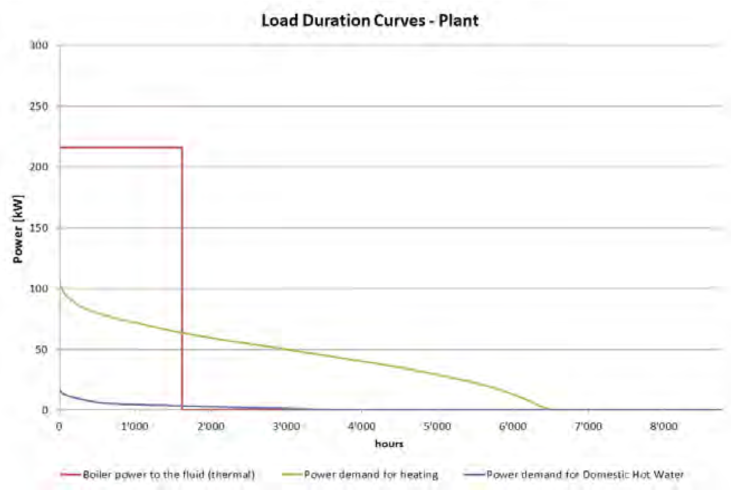


- Stand-by + firing losses: 26.5 kWh/m²/y
- Distribution losses: 4.0 kWh/m²/y
- Peak heating + DHW demand: 64 kW
- Heat Pump Thermal Peak power: 84 kW

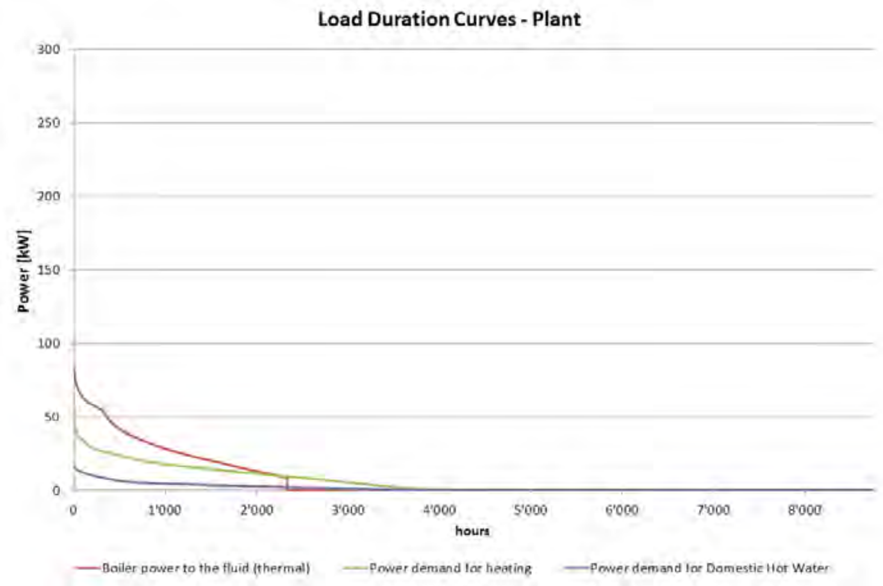
1. **Paris Comparison - Energy**
1.9. Boiler Refurbishment Strategies - Sizing comparison

The load duration curves after different refurbishment strategies are gathered on this page.

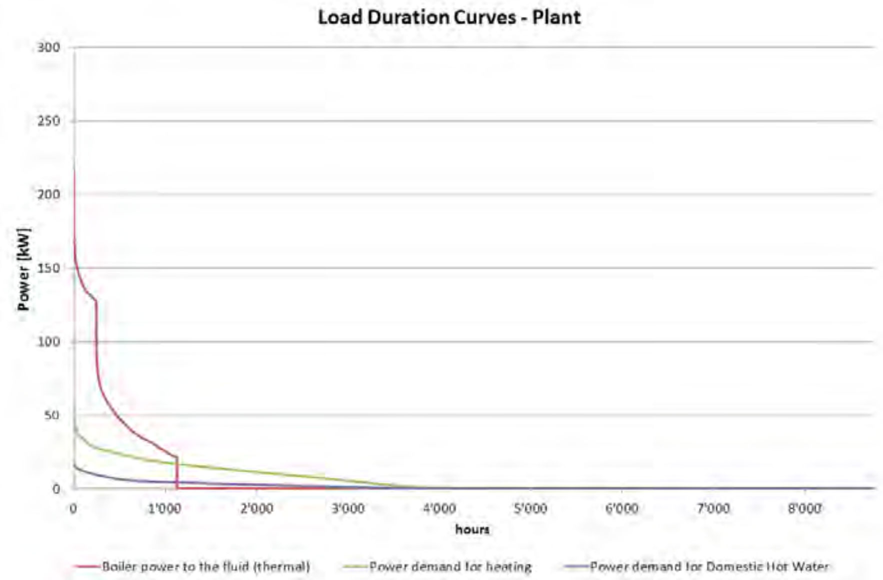
UNREFURBISHED BULDING



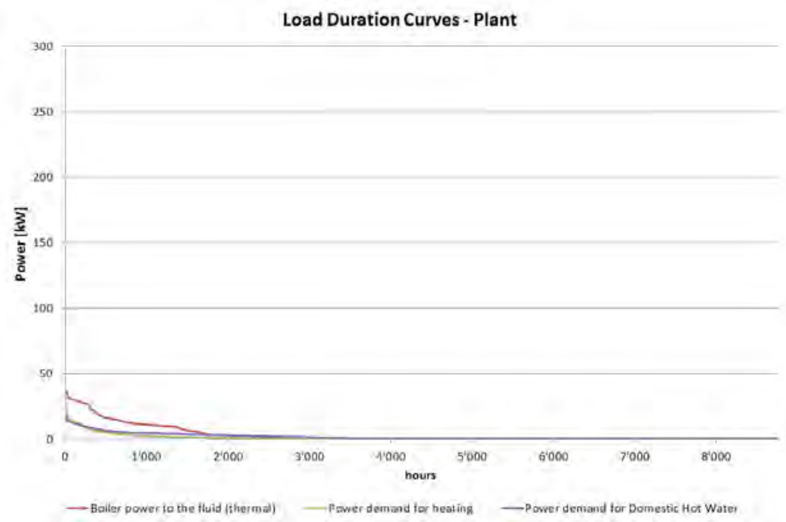
STRATEGY 1. Envelope First, Level GOOD, then new BOILER



STRATEGY 2. Boiler First, then Envelope, level GOOD



STRATEGY 3. Envelope First, Level EXCELLENT, then new BOILER



Remarks

In all 3 cases, the building envelope and boiler room have been refurbished.

The order in which the refurbishment has been done has an impact on the boiler equipment sizing.

When refurbishing the boiler first, a new boiler has to be installed which has the same peak power as before. As it is equiped with a modulating burner, it can adapt to the new the heating demand profile once the building envelope has been refurbished.

When refurbishing the envelope first, the new boiler size can be reduced, as the heating peak power demand has been reduced. Compared to the "Boiler first strategy", this translates into:

- investment cost savings
- maintenance costs savings
- grey energy savings

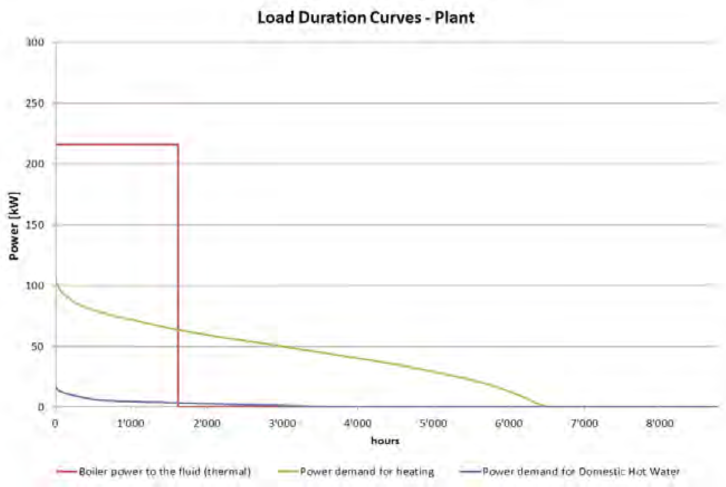
Moreover, in some countries like France, if the boiler size is small enough (lower than 70kW), the fire safety regulations are reduced for the boiler room, which can translate into further investment and maintenance costs savings.

1. **Paris Comparison - Energy**

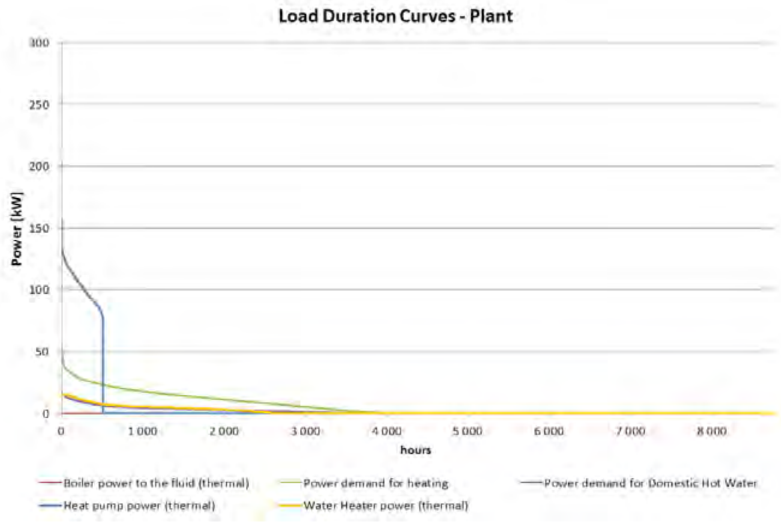
1.10. Heat Pump Refurbishment Strategies - Sizing comparison

The load duration curves after different refurbishment strategies are gathered on this page.

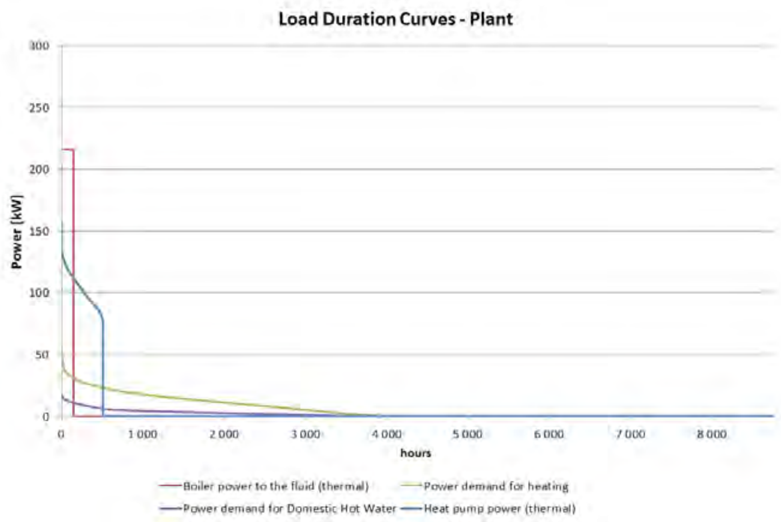
UNREFURBISHED BULDING



STRATEGY 4. Envelope First, Level GOOD, then HEAT PUMP



STRATEGY 5. HEAT PUMP first, then Envelope, level GOOD



Remarks

With an unrefurbished envelope, it is not possible to install a heat pump that can cover all heating demand for the following reasons:

- the existing radiators require a high temperature regime (80°C) to cover the high heat losses, which is difficult to supply with a heat pump
- heat pumps are less efficient with low air temperature. An unrefurbished building would require numerous high-power heat pumps to cover all heating demand.

As a consequence, when installing the heat pump first, the old boiler has to be kept to handle the the winter season and the domestic hot water preparation. During this stage, the heat pump is only used when the outside air temperature is high enough (7°C).

In comparison, refurbishing the envelope first, is very interesting when a heat pump is going to be installed. Indeed, reducing first the heating demand via an improved envelope performance makes it possible, in a second step, to install a heat pump that can cover all heating demand. Another heat pump is installed to handle domestic hot water preparation.

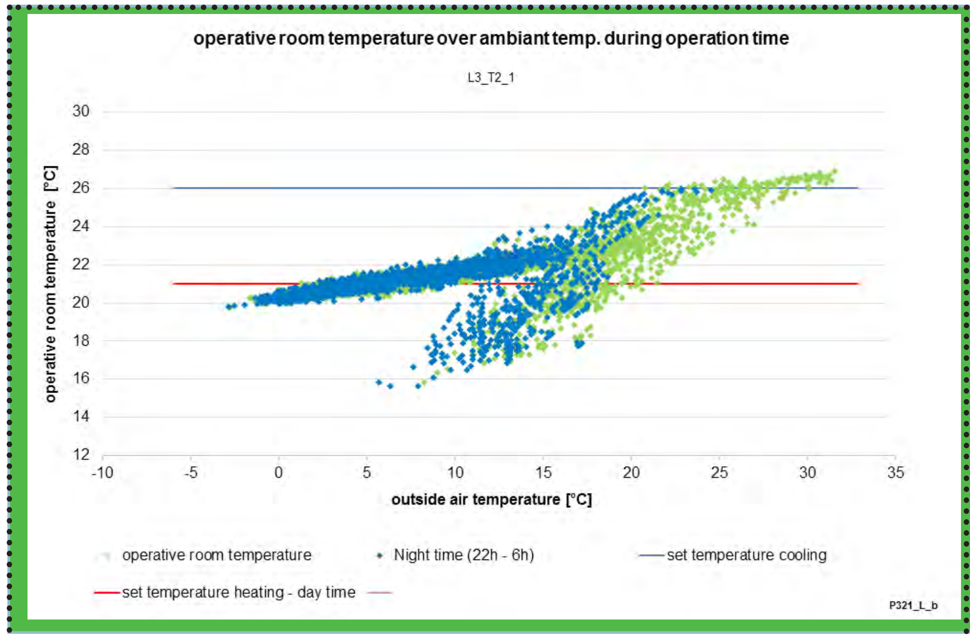
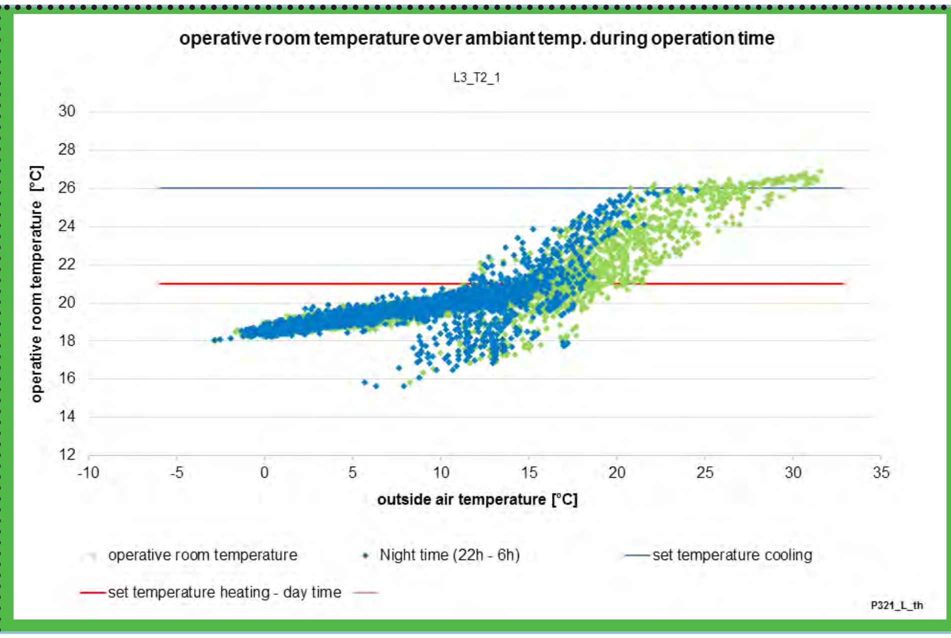
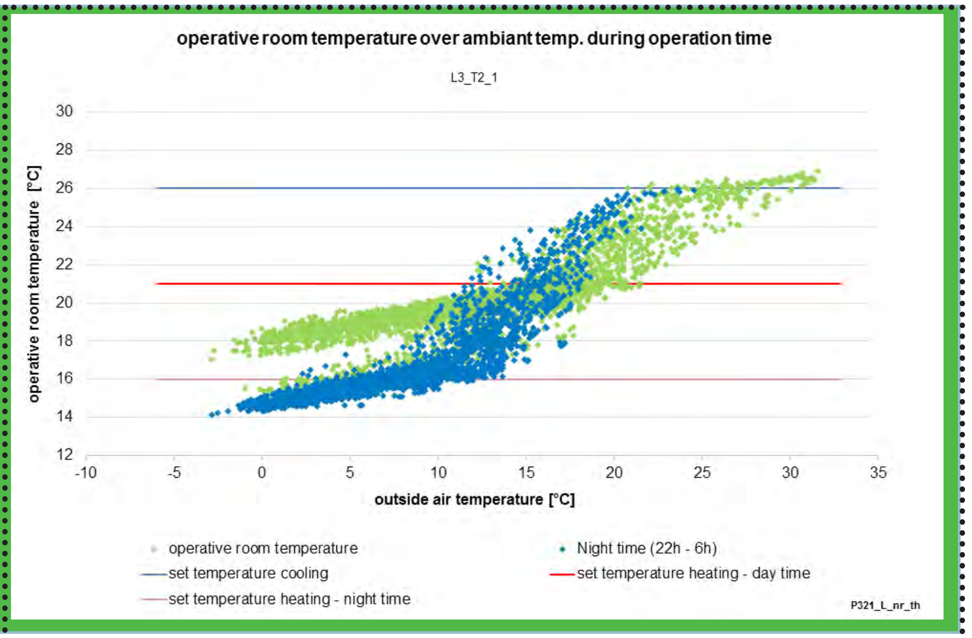
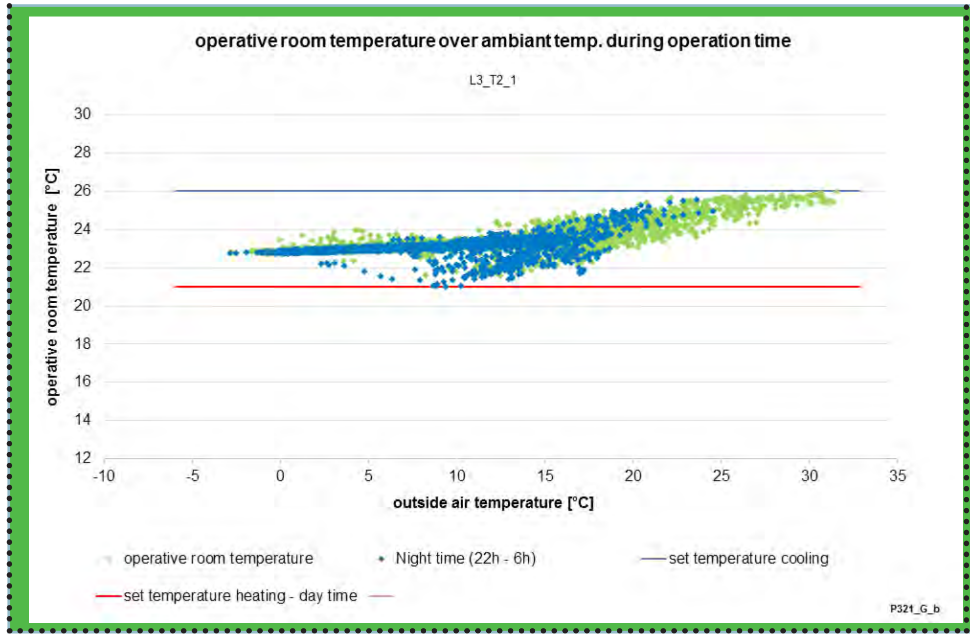
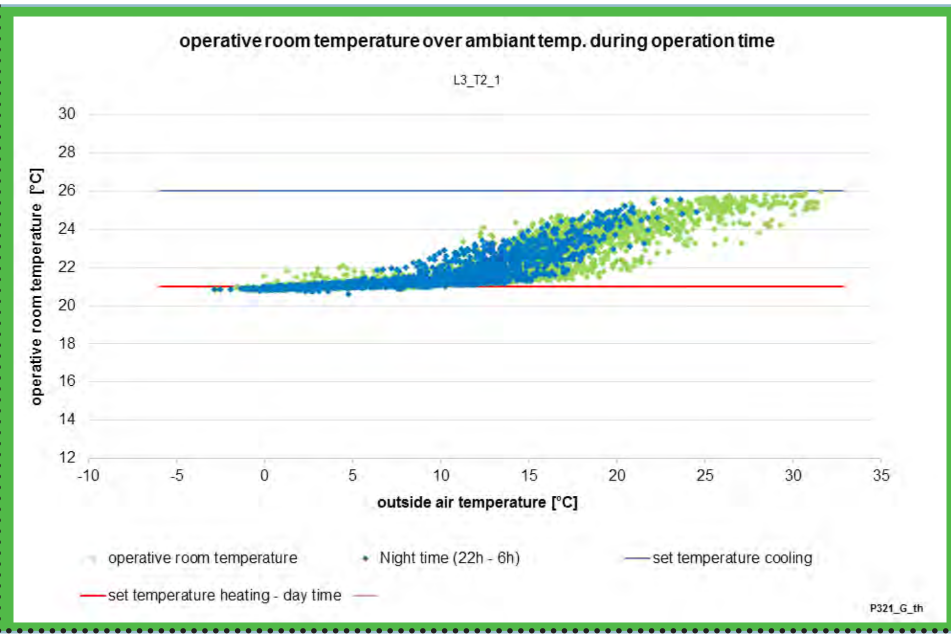
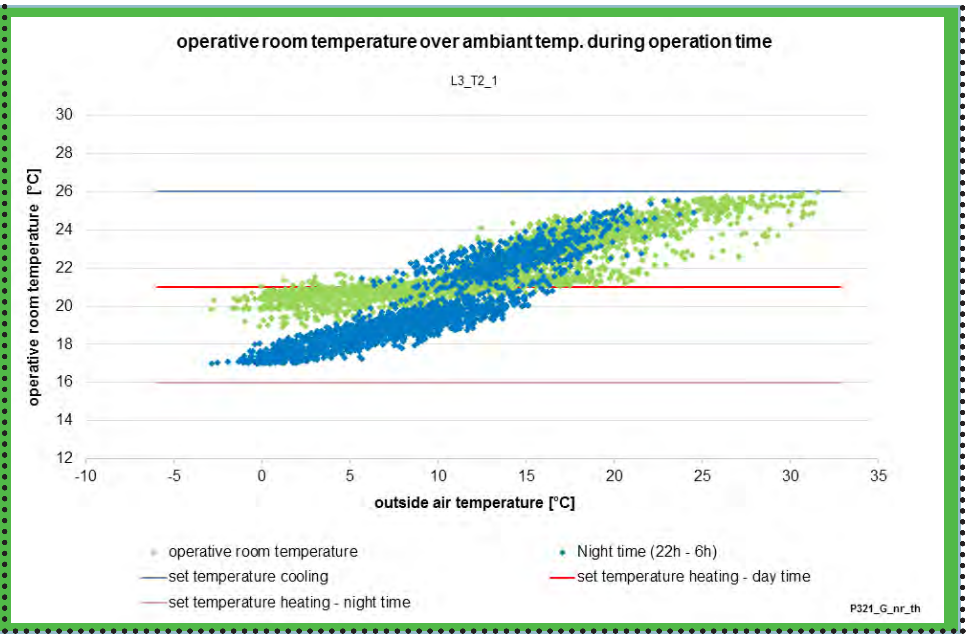
In the end, both strategies end up with the same heat pump to cover heating demand. In the “Envelope First” strategy, it is also possible to install a separate heat pump to produce domestic hot water, whereas with the “Heat Pump First” strategy, the old boiler has to be kept as long as the envelope has not been refurbished.

It is important to underline then that this “Heat Pump First” strategy is only working if there is still a fully-fonctionning boiler able to supply heat for domestic hot water and high heating loads. If a boiler is broken in a poorly insulated building, it is really difficult to replace it only by a heat-pump.

2. Paris Climate - Comfort

2.1. Yearly Comfort

Operative temperature is frequently associated with the real temperature felt by the human body in indoor environment. It takes into account air temperature and temperature of surrounding surfaces. Each point of the graphs below represents one hour of the year, the point's abscissa is the ambient temperature at this time of year, its ordinate is the correspondent operative temperature inside. To achieve comfort, the points must be in between red and blue lines.

	No thermostats On Radiators	Thermostat On Radiators	Night Time Reduction, Thermostat On Radiators
Low Envelope			
Good Envelope			

The first column considers only basic radiators without thermostatic valves. It can be seen that increasing envelope performance from "base" to "good" reduces cold wall radiative effects and increases operative temperature by up to 3°C in winter.

Some lower operative temperature can be observed for outside air temperature between 10°C and 20°C. These points correspond to the period where central heating is shut off (June to August). When the envelope is poorly insulated, it leads to low operative temperature for cool summer nights.

The second column shows the impact of implementing thermostats on radiators. Using thermostats on radiators helps to ensure the 21°C room air temperature set point. As a consequence, implementing this local control can reduce the operative temperature in the room by approx. 3°C compared to the previous variants, as the radiators do not tend to overheat.

For a poorly-insulated wall, this can lead to lower operative temperatures and discomfort due to low surface temperatures. Whereas, for a good-insulated envelope, operative temperature stays in the comfortable range. This illustrates the need to combine good envelope refurbishment with a good control strategy for the emitters in order to ensure high thermal comfort and low energy demand.

Night time reduction decreases operative temperature by 4 to 5 °C during sleep time. In theory, as occupants are sleeping, it does not always translate in discomfort.

But as poorly-insulated buildings suffer from cold wall radiative effects in winter, this 21°C room air temperature leads to a 18°C operative temperature in daytime and less than 15°C operative temperature during sleep time. There is a high chance that this phenomenon creates discomfort and will bring the occupant to increase the room air temperature set point, compensating the energy savings made with the room thermostat.

It is also important to note that these low temperatures may translate into building pathologies like condensation, mould, etc.

For well-insulated building, the operative temperature stays in a comfortable range during night time, as there is no cold-wall phenomenon.

2. Paris Climate

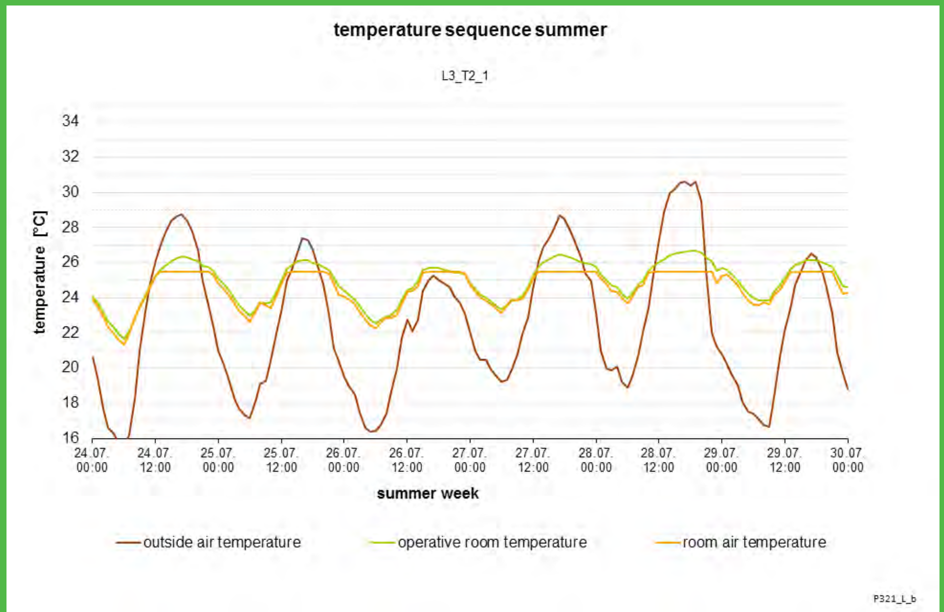
2.2. Comfort - Active Cooling for summer comfort

The following charts display the evolution of air and operative temperature during a typical summer week in the current Paris climate, without consideration for heat island effect.

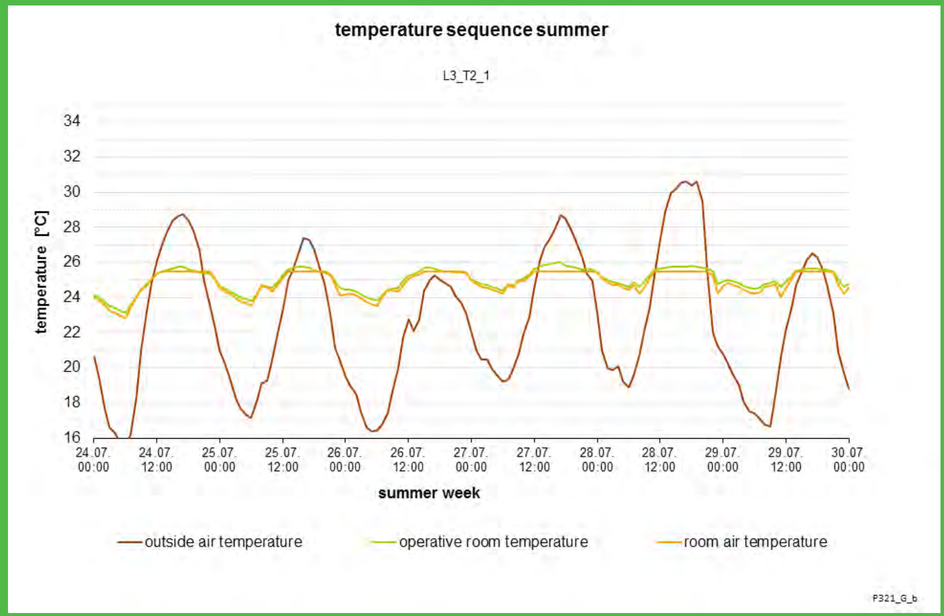
Two variants are presented, one with a Low envelope performance, the other one with a Good envelope performance. Both of them are actively cooled by split units that ensure a maximum 26°C air temperature during day and night.

It is important to note that, in this simulation, the split systems are ON all day long. Shutting them OFF during daytime (when nobody is in the apartment) would reduce the energy demand, but also increase the overall peak demand, as a higher power would be needed to cool down the room at the end of the day, when people are back from work

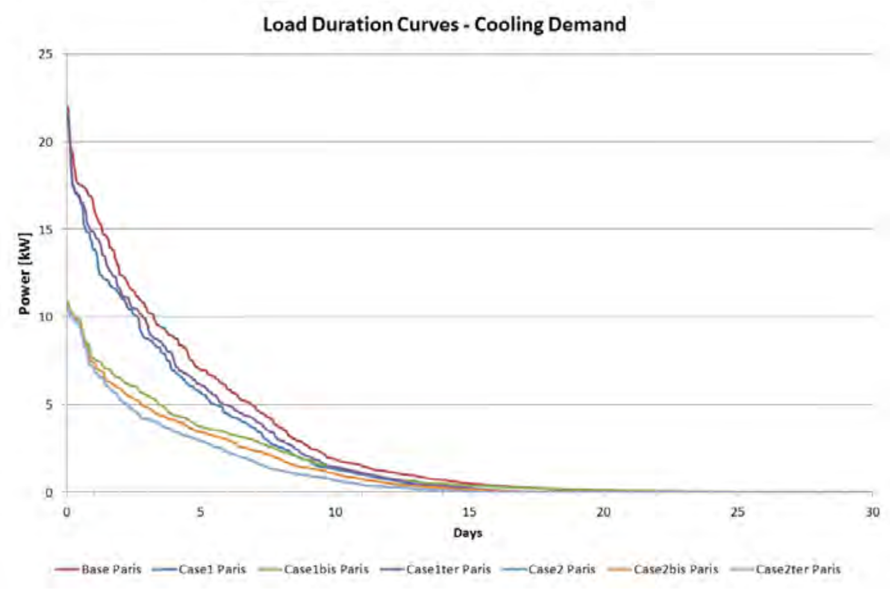
Low Envelope Performance, Active cooling



Good Envelope Performance, Active cooling



Load Duration Curves - Cooling Demand



Increasing the envelope performance from a "base" level to a "good" level includes:

- increasing shading and glazing solar control efficiencies,
- reducing outside air infiltrations
- implementing efficient roof insulation

As a consequence, cooling peak loads are reduced by 52% (-11 kW).

With this mild Parisian weather data, there are heat waves period where cooling strategies seem to be required. Hence, the related energy demand for cooling is limited, but without it, comfort issues would appear.

This active cooling demand could have been met partially by passive cooling strategies like nighttime natural ventilation.

This strong sizing reduction can also play a role to limit the urban heat island effect that tends to increase the air temperature downtown in summer. As more and more buildings are equipped with air conditioning devices, more and more heat is rejected in the urban area during night time. It is important to precise that this phenomena has not been taken into account in the calculation. Reducing the size of air conditioning equipment will help to limit this phenomena, while also giving the possibility not to use any of these active systems if passive measures can be implemented.

With efficient solar control strategies such as the one implemented with the good envelope performance, the maximum operative temperature is reduced by 1°C during the day. This difference is mainly due to reduced surface temperature (essentially window and ceiling surfaces), as the newly implemented solar control strategies tend to limit the amount of solar gains entering the occupied space.

During the night, well-insulated buildings tend to release less heat stored in their inertia and get 1°C warmer. It is important to remind here that no natural ventilation during nighttime has been implemented here. This would be an efficient solution to release heat from the building inertia.

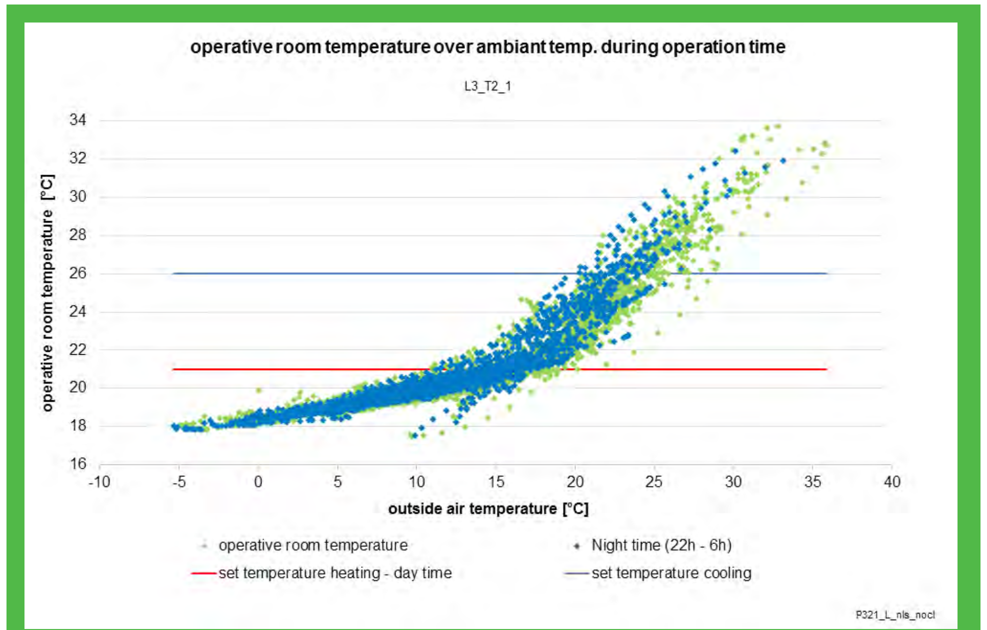
2. Paris Climate

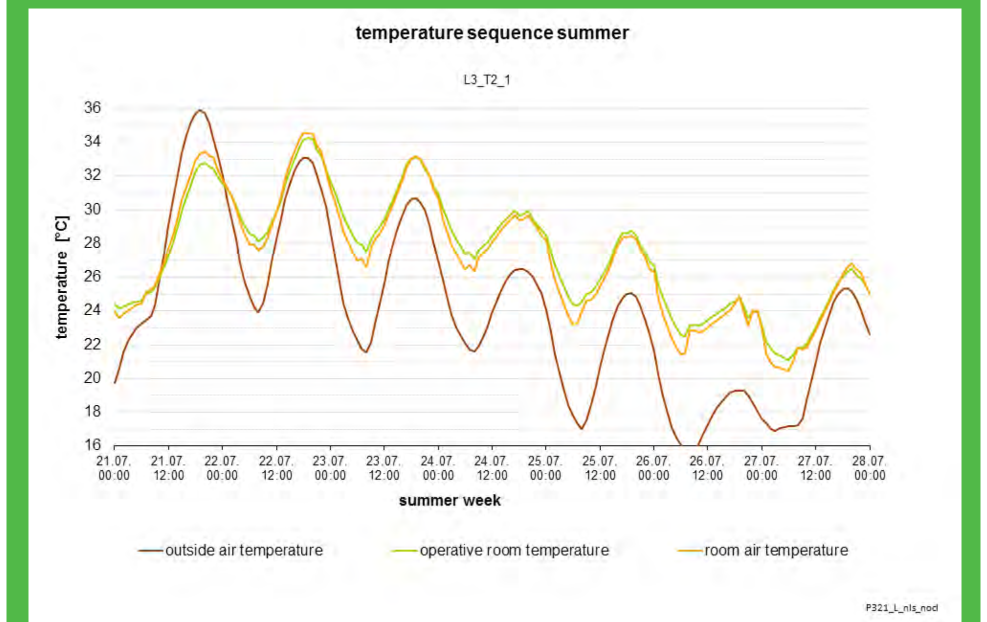
2.3. Comfort - Passive Cooling for summer comfort

The following variants have been calculated with a parisian weather data considering a summer heat wave.

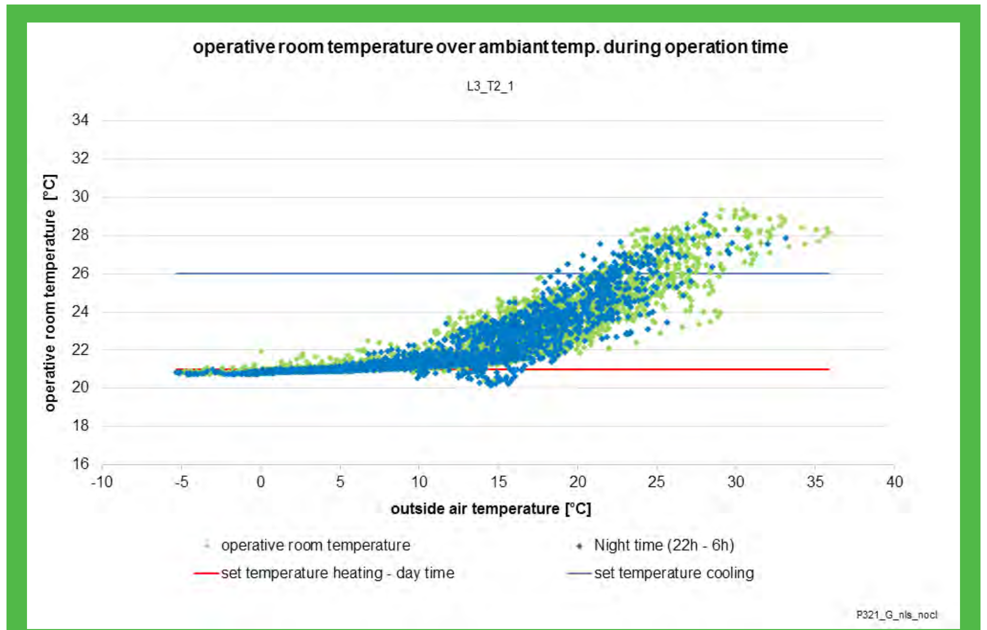
No active space cooling has been taken into account for these variants. But nighttime natural ventilation (by window opening) has been considered as a passive cooling strategy.

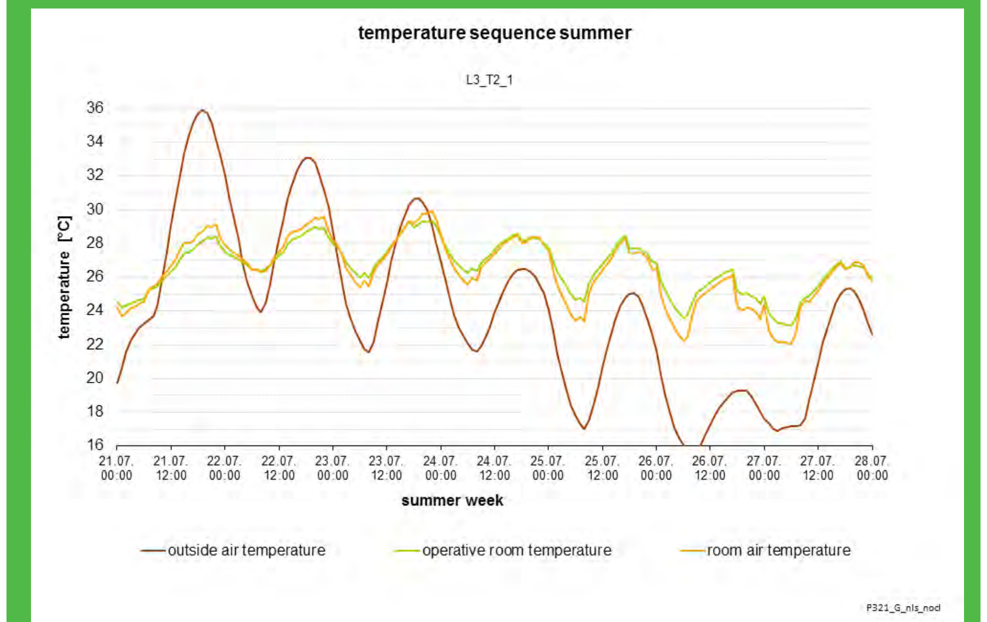
Low Envelope Performance, No Active Cooling



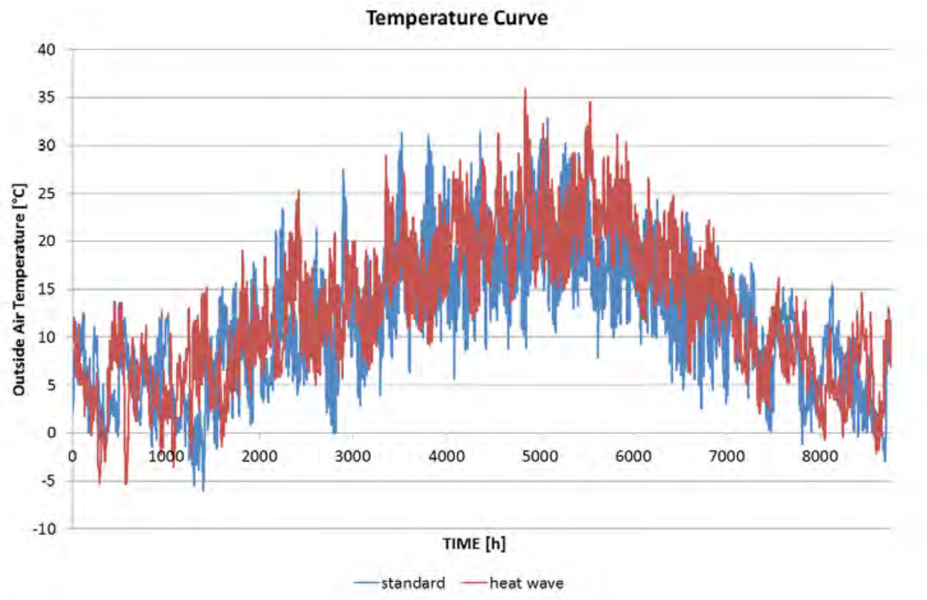


Good Envelope Performance, No Active cooling





Comparison between Standard Weather and "Heat Wave" Weather Data



The new weather data shows high outside air temperatures (>34°C). As the rooms are not equipped with active cooling systems, these outdoor conditions lead to high indoor temperatures.

There is a clear improvement in terms of summer comfort when comparing the low envelope with the good one. Thanks to:

- increased thermal insulation
- better solar control glazing
- and external solar protection (like shutters)

climate heat gains are limited and indoor operative temperature is reaching 29°C maximum. This is a clear example where improving envelope performance leads to higher thermal comfort in summer. Combined with an elevated air speed strategy (ceiling fan, desk fan, etc.) and low clothing factor (shorts and T-shirt), this solution can lead to thermally comfortable spaces.

In comparison, it is very difficult to ensure a good comfort level inside the room with an operative temperature above 32°C, as the low envelope variant is displaying. In this situation, high thermal stress can be expected.

Night time ventilation is very important to unload the thermal energy stored in the building inertia during the day. Thanks to daytime/nighttime temperature amplitude, the room does not tend to progressively overheat during an extended hot summer week.

NB: It is important to underline that Urban Heat Island effect is not completely taken into account with this weather data, which can reduce the passive cooling potential of this strategy.

3. Climates Comparison

3.1. Results Summary (area specific)

BOUNDARY CONDITIONS	Base Naples	Case2 Naples	Case3 Naples	Base Paris	Case2 Paris	Case3 Paris	Base Helsinki	Case2 Helsinki	Case3 Helsinki
Climate	Naples	Naples	Naples	Paris	Paris	Paris	Helsinki	Helsinki	Helsinki
Envelope performance	Low	Good	Excellent	Low	Good	Excellent	Low	Good	Excellent
Night time reduction	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Thermostat on radiators	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Split unit	Old	New	New	Old	New	New	Old	New	New
Boiler	Old	New	New	Old	New	New	Old	New	New

RESULTS		Base Naples	Case2 Naples	Case3 Naples	Base Paris	Case2 Paris	Case3 Paris	Base Helsinki	Case2 Helsinki	Case3 Helsinki
Energy demand										
Zone Heating demand	kWh/m²/y	249,3	36,6	5,9	290,9	47,4	7,8	256,5	39,1	17,1
Hot water demand	kWh/m²/y	10,5	10,5	10,5	12,6	12,6	12,6	15,1	15,1	15,1
Cooling demand	kWh/m²/y	24,7	6,8	5,1	2,0	0,8	0,7	-	-	-
Electricity demand	kWh/m²/y	52,8	39,0	38,9	53,5	38,4	39,2	52,8	42,8	40,6
Total	**kWh/m²/y**	**337,3**	**92,9**	**60,4**	**359,0**	**99,3**	**60,3**	**324,4**	**97,1**	**72,8**
Final Energy Consumption										
Gas - Heating	kWhFE/m²/y	304,5	37,9	5,9	358,3	49,7	7,9	316,4	40,8	17,6
Gas - Domestic Hot Water	kWhFE/m²/y	12,9	10,9	10,6	15,6	13,2	12,8	18,7	15,8	15,6
Gas - Generation and supply losses	kWhFE/m²/y	49,0	6,4	4,8	45,5	7,3	5,0	40,0	7,5	5,7
Electricity consumption - Auxiliaries EPBD	kWhFE/m²/y	43,7	22,0	21,6	36,0	20,3	21,1	34,6	24,6	22,4
Total	**kWhFE/m²/y**	**410,0**	**77,2**	**42,9**	**455,5**	**90,5**	**46,9**	**409,7**	**88,6**	**61,2**
Primary Energy Consumption										
Gas consumption	kWhPE/m²/y	498,3	75,1	29,0	570,4	95,4	35,0	510,1	87,1	52,8
Electricity consumption	kWhPE/m²/y	144,5	72,8	71,4	119,3	67,2	69,9	114,5	81,3	74,1
Total	**kWhPE/m²/y**	**642,8**	**147,8**	**100,4**	**689,7**	**162,6**	**104,9**	**624,6**	**168,4**	**126,9**
CO2 Emissions										
Gas emissions	kgCO2eq/m²/y	307,4	46,3	17,9	352,0	58,9	21,6	314,8	53,7	32,6
Electricity emissions	kgCO2eq/m²/y	40,0	20,2	19,8	33,0	18,6	19,4	31,7	22,5	20,5
Total	**kgCO2eq/m²/y**	**347,5**	**66,5**	**37,7**	**385,0**	**77,5**	**41,0**	**346,5**	**76,3**	**53,1**

Primary Energy Factor Europe (source: ISO15603:2008)

Electricity 3.31

Natural Gas 1.36

CO2 emission Factor Europe (source: ISO15603:2008)

Electricity 617 kgCO2eq/kWh

Natural Gas 277 kgCO2eq/kWh

BOUNDARY CONDITIONS	Base Naples	Case2 Naples	Case3 Naples	Base Paris	Case2 Paris	Case3 Paris	Base Helsinki	Case2 Helsinki	Case3 Helsinki
Climate	Naples	Naples	Naples	Paris	Paris	Paris	Helsinki	Helsinki	Helsinki
Envelope performance	Low	Good	Excellent	Low	Good	Excellent	Low	Good	Excellent
Night time reduction	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Thermostat on radiators	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Split unit	Old	New	New	Old	New	New	Old	New	New
Boiler	Old	New	New	Old	New	New	Old	New	New

RESULTS		Base Naples	Case2 Naples	Case3 Naples	Base Paris	Case2 Paris	Case3 Paris	Base Helsinki	Case2 Helsinki	Case3 Helsinki
Energy demand										
Zone Heating demand	MWh/y	263	39	6	306	50	8	270	41	18
Hot water demand	MWh/y	11	11	11	13	13	13	16	16	16
Cooling demand	MWh/y	26	7	5	2	1	1	-	-	-
Electricity demand	MWh/y	56	41	41	56	40	41	56	45	43
Total	**MWh/y**	**355**	**98**	**64**	**378**	**105**	**64**	**342**	**102**	**77**
Final Energy Consumption										
Gas - Heating	MWhFE/y	321	40	6	378	52	8	333	43	19
Gas - Domestic Hot Water	MWhFE/y	14	11	11	16	14	13	20	17	16
Gas - Generation and supply losses	MWhFE/y	52	7	5	48	8	5	42	8	6
Electricity consumption - Auxiliaries EPBD	MWhFE/y	46	23	23	38	21	22	36	26	24
Total	**MWhFE/y**	**432**	**81**	**45**	**480**	**95**	**49**	**432**	**93**	**64**
Primary Energy Consumption										
Gas consumption	MWhPE/y	525	79	31	601	101	37	538	92	56
Electricity consumption	MWhPE/y	152	77	75	126	71	74	121	86	78
Total	**MWhPE/y**	**677**	**156**	**106**	**727**	**171**	**111**	**658**	**177**	**134**
CO2 Emissions										
Gas emissions	tCO2eq/y	324	49	19	371	62	23	332	57	34
Electricity emissions	tCO2eq/y	42	21	21	35	20	20	33	24	22
Total	**tCO2eq/y**	**366**	**70**	**40**	**406**	**82**	**43**	**365**	**80**	**56**

Primary Energy Factor Europe (source: ISO15603:2008)

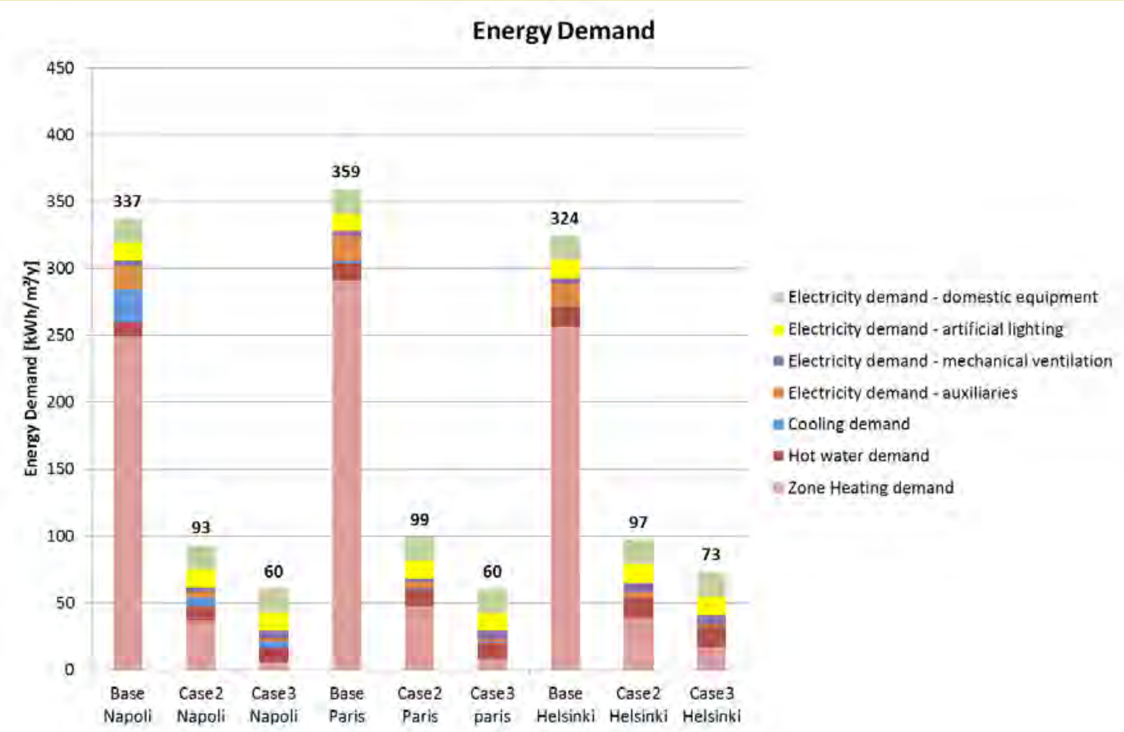
Electricity	3.31
Natural Gas	1.36

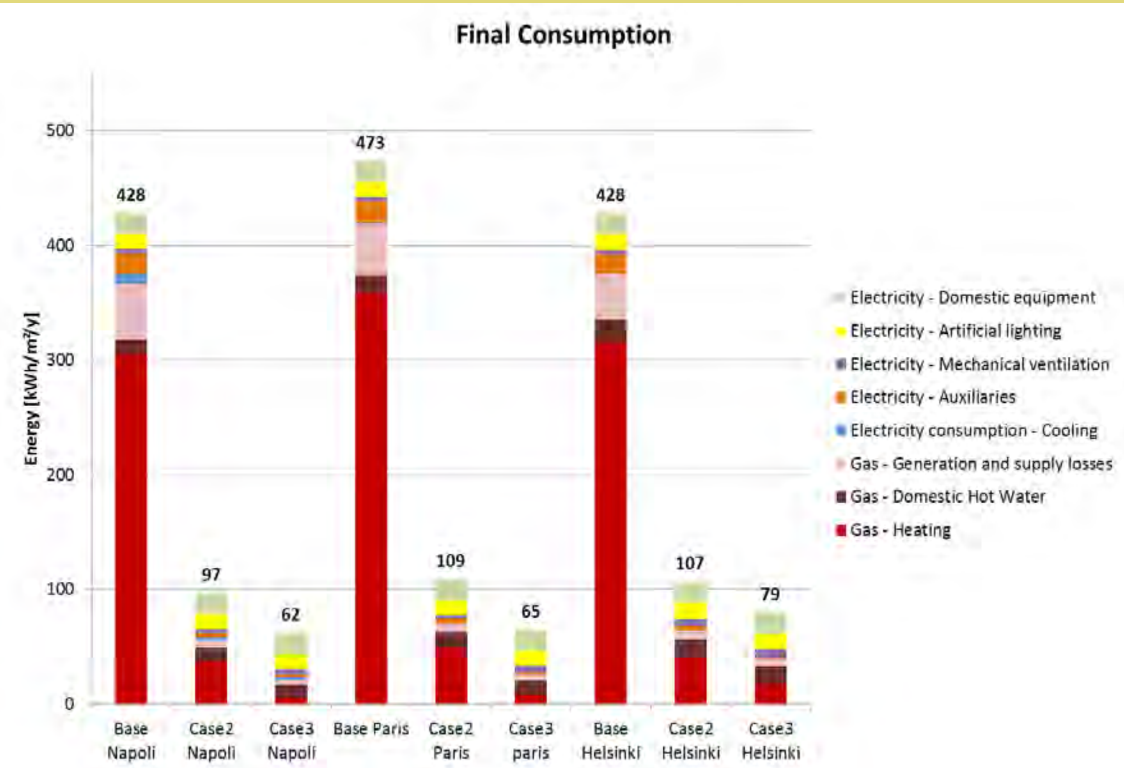
CO2 emission Factor Europe (source: ISO15603:2008)

Electricity	617 kgCO2eq/kWh
Natural Gas	277 kgCO2eq/kWh

3.3. Energy Demand and Final Energy Consumption

The following results compare different envelope performance variants for 3 representative european climates.





LEGEND

Base: Low Envelope Performance, No Control, Old Boiler, Low efficiency split unit. Plant dimensioned on the low envelope demand.

Case 2: Good Envelope Performance, Nighttime Reduction, Thermostat on Radiators, New Boiler. High efficiency split unit. Plant dimensioned on good envelope demand.

Case 3:Excellent Envelope Performance, Nighttime Reduction, Thermostat on Radiators, New Boiler, High efficiency split unit. Plant dimensioned on the excellent envelope.

Two other climates have also been considered to study whether the previous conclusions were specific to France, or could also be applied to other european areas. As a reminder, the base case variants have been defined according to an estimation of the envelope performance of the local existing building stock. As a consequence, the building envelopes differ between the three climates, as they tend to do in reality.

The Helsinki Base variant presents the lowest energy demand between the 3 different climates. As Finland has been implementing for a longer time energy-efficient regulations for buildings, the envelope performance chosen for its base case is increased compared to France and Italy.

For that same reason, Naples shows a high heating demand, as its envelope is the least performant from the 3 Climates.

In order to better understand the previous remarks, the following table illustrates the correlation between climate, envelope performance and heating demand.

	Naples	Paris	Helsinki	Comments
Heating Degree Day (15°C) [Kd]	1649	2931 (+77%)	4941 (+200%)	Characterizes how cold the climate is
Ubuilding [W/m²/K] **(EN15603 definition)**	3.29	2.04	1.04	Characterizes how much heat is lost through the envelope
1/Ubuilding [m².K/W]	0.30	0.49 (+63%)	0.96 (+220%)	Characterizes how well insulated the envelope is
Heating Demand [kWh/m²/y]	249	291 (+17%)	257 (+3%)	Space heating demand for the building

The limited differences between each climate heating demand are due to the different envelope performance which increases when the climate is colder. As an example, the Paris climate is 77% colder than the Naples one (speaking of heating degree days), but also 63% better insulated. As a consequence, the building heating demand in Paris is only 17% higher than in Naples.

It is important to note that in all three climates, the base envelope performance leads to a final heating energy consumption higher than 250 kWhEF/m²/y. Hence, improving the envelope performance makes sense for all three climates.

It could be argued that in Italy, buildings are not heated up to 21°C (air temperature) in winter, which would reduce the heating energy demand for this climate. However, reducing the heating temperature setpoint to, say 19°C (air temperature) for Naples climate only leads to a 20% reduction for the heating demand. Hence, the previous statements stay also true with this hypothesis.

NB: It is important to notice that electrical demand for domestic equipment is limited (18.2 kWh/m².y) which translates an eco-friendly behavior from the building occupants. As a consequence, heating demand is slightly increased. This domestic equipment is not taken into account in the summary tables, because it is not tackled by EPBD directives. It is coherent to show these gains here because they have a positive role in heating demand reduction in winter.

4. ANNEX I: Detailed Results

4. Annex I: Detailed Results

4.1. Base Case: Low Envelope, No Control

Control: No Control

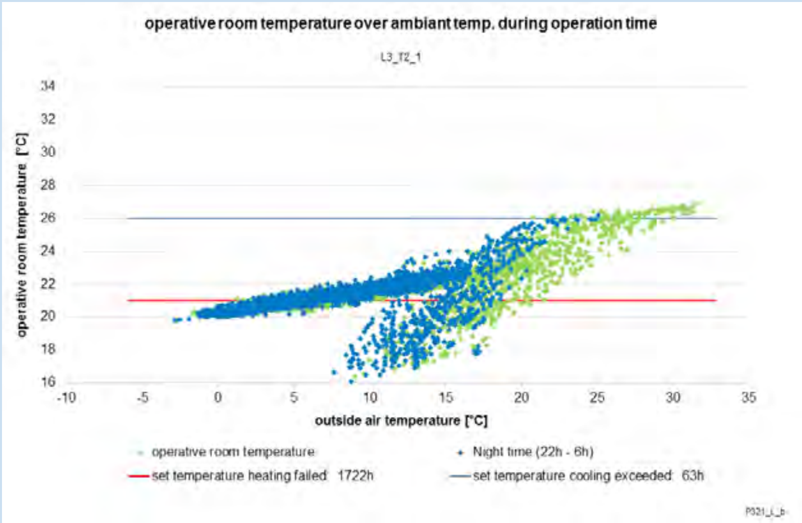
Envelope Perfomance: Low

Heating: Old Boiler - 1 speed burner

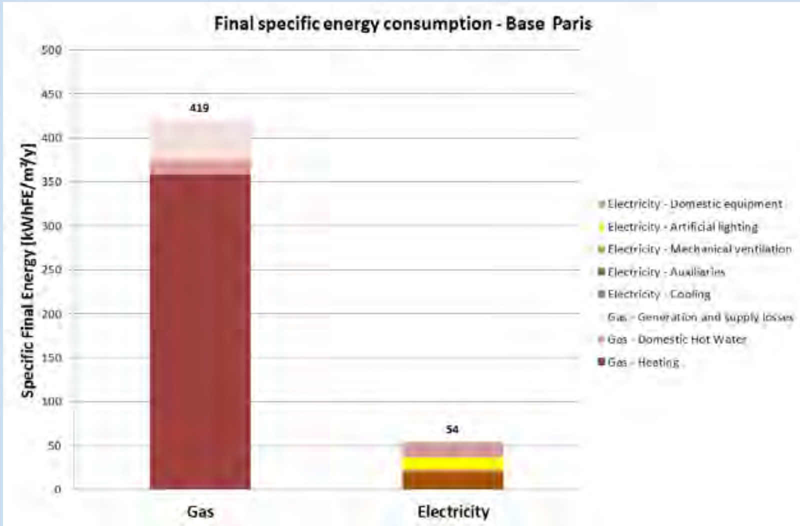
Cooling: Split unit for cooling (low efficiency)

Plant sized following the low envelope demand

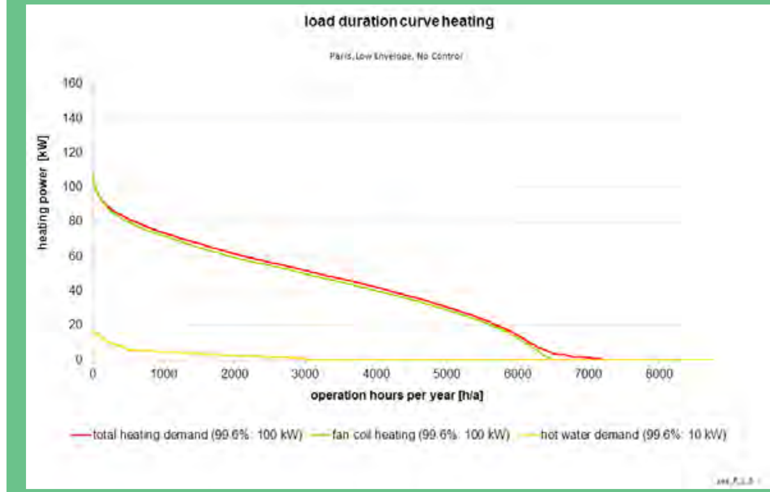
Comfort - Apartment L3_T2 (3rd floor, 2 rooms, SE-SW)

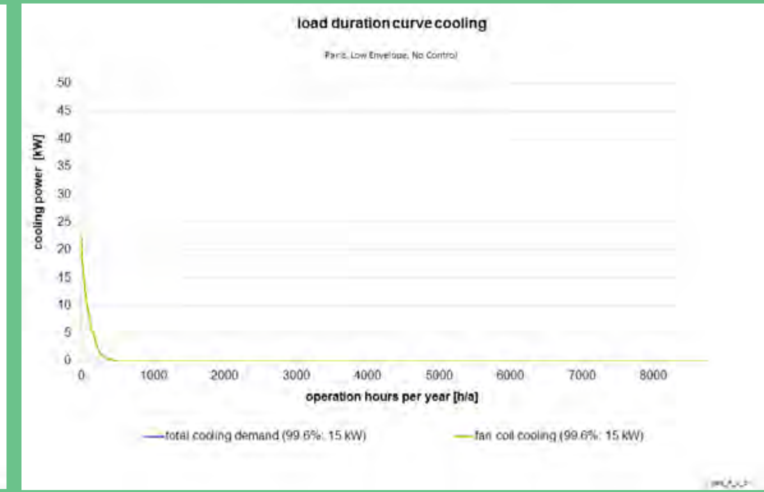


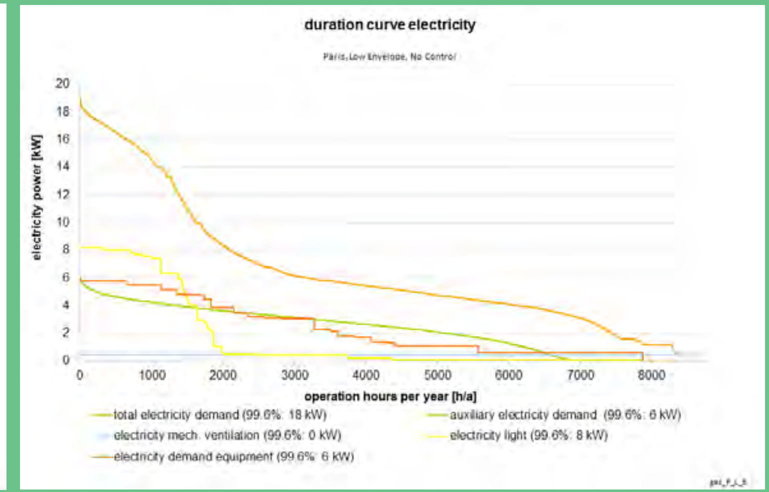
Final Specific Energy Consumption

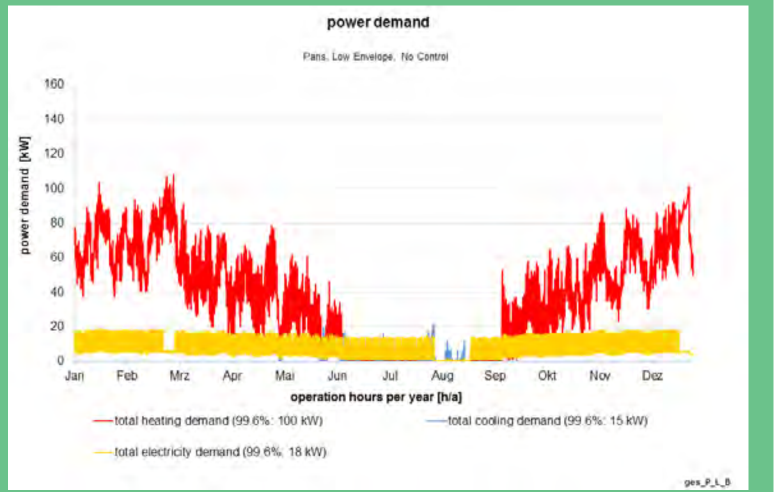


Energy Demand - Load Curves

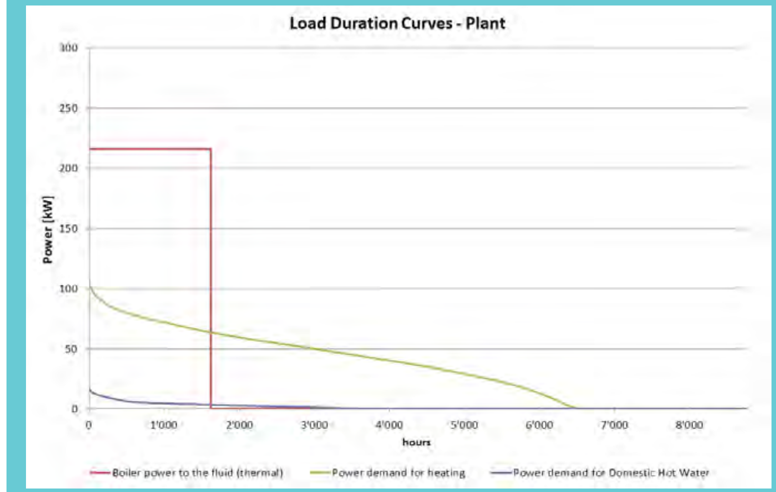


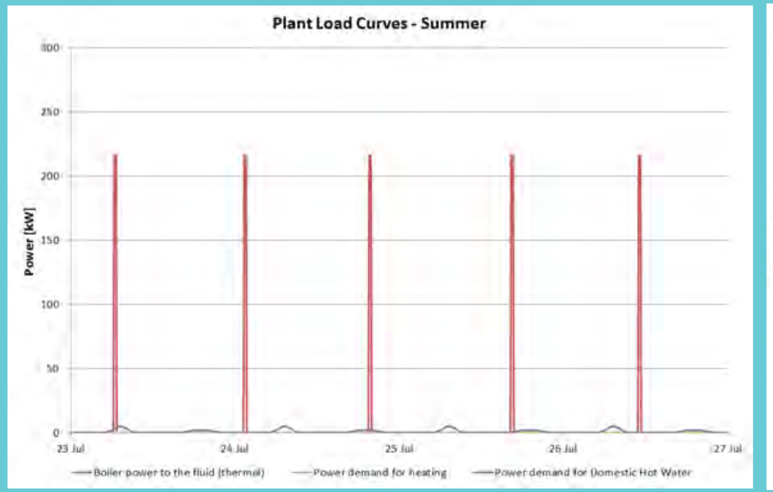


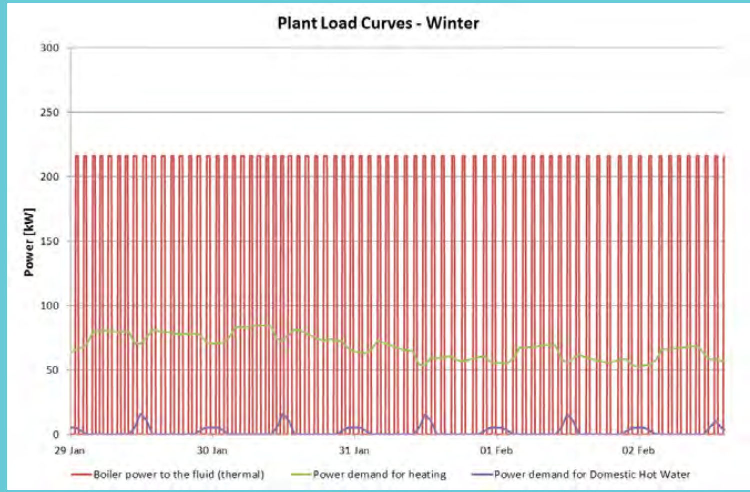




Plant Model - Load Curves







	Unit	Gas	Electricity	Total
Final Energy consumption	kWhFE/m²/y	419.4	54.3	**473.7**
Primary Energy consumption	kWhPE/m²/y	419.4	140.0	**559.5**
CO2 Emissions	kgCO2eq/m²/y	101.9	4.5	**106.4**

4.2. Paris - Case 1: Low Envelope, Night Time Reduction, Thermostat on Radiators

Control: Nighttime reduction, Thermostat on Radiators

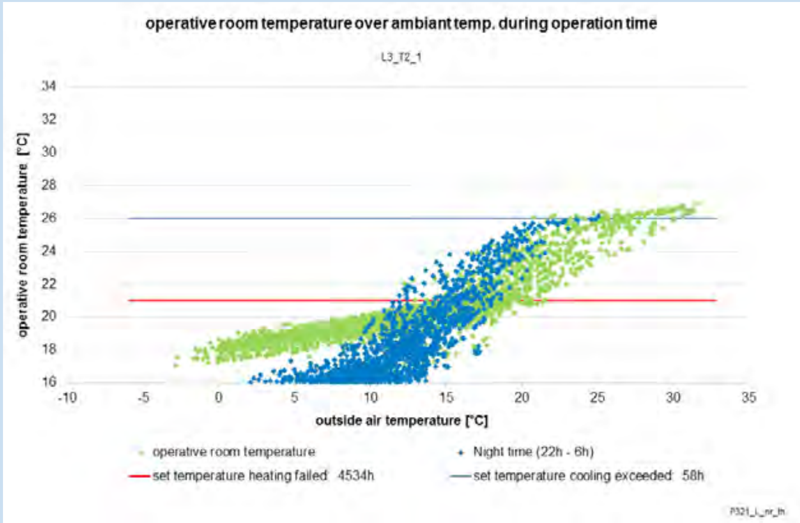
Envelope Perfomance: Low

Heating: Old Boiler - 1 speed burner

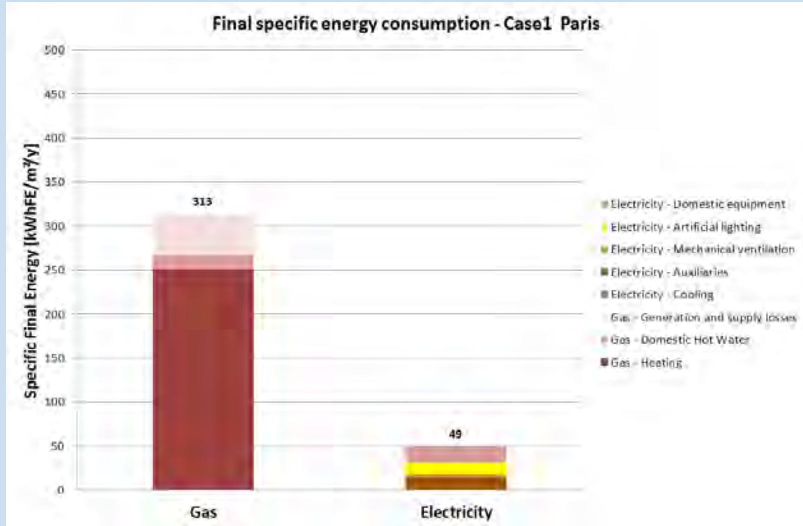
Cooling: Split unit for cooling (low efficiency)

Plant sized following the low envelope demand

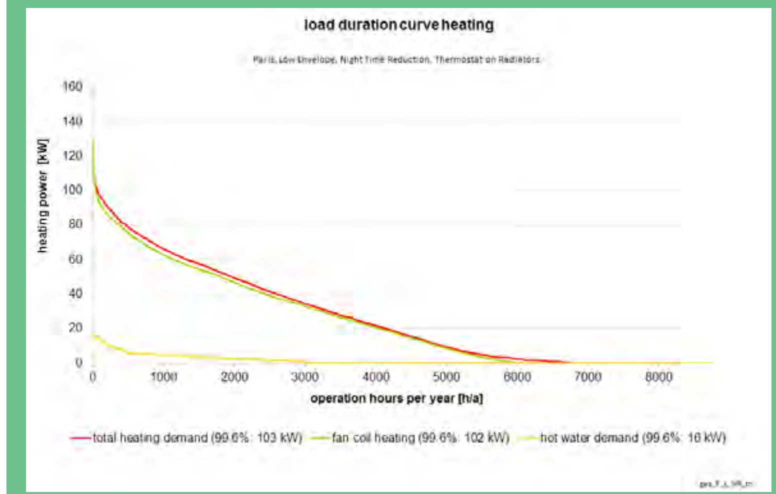
Comfort - Apartment L3_T2 (3rd floor, 2 rooms, SE-SW)

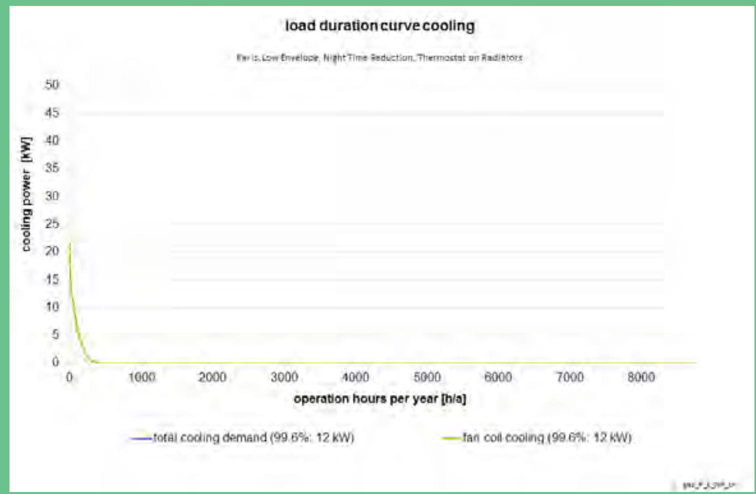


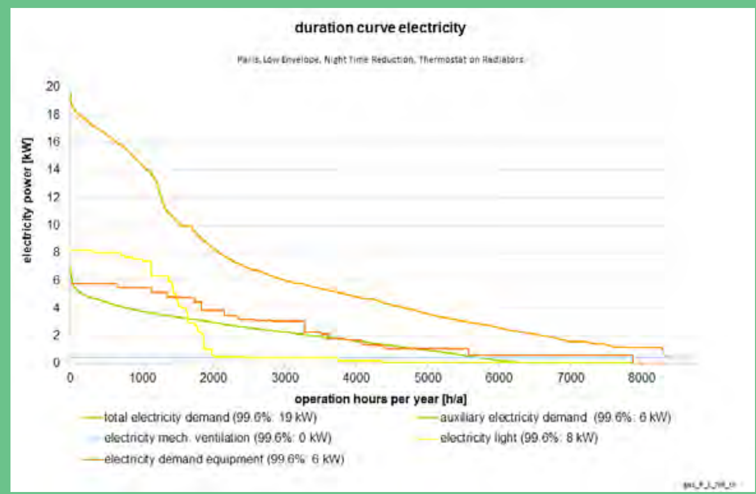
Final Specific Energy Consumption

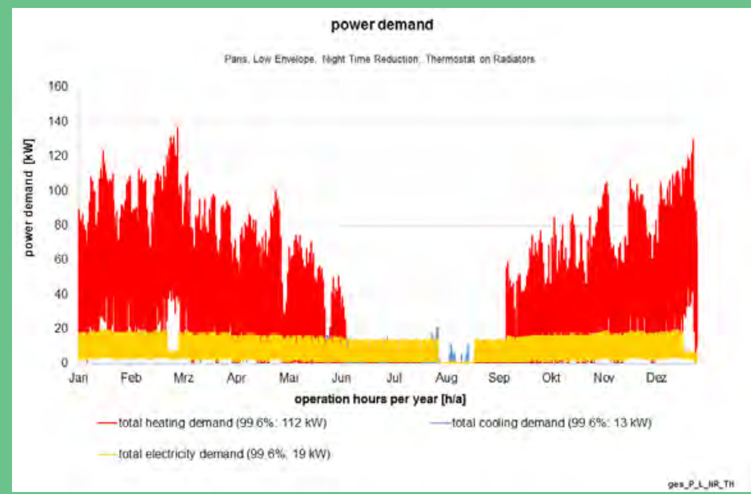


Energy Demand - Load Curves

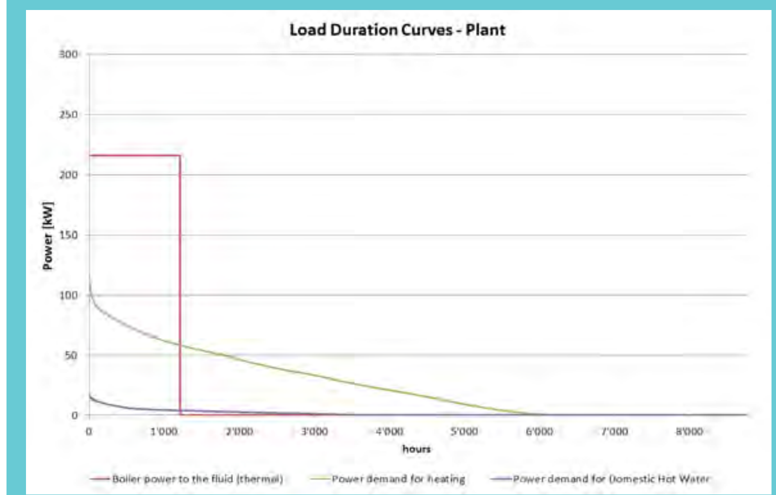


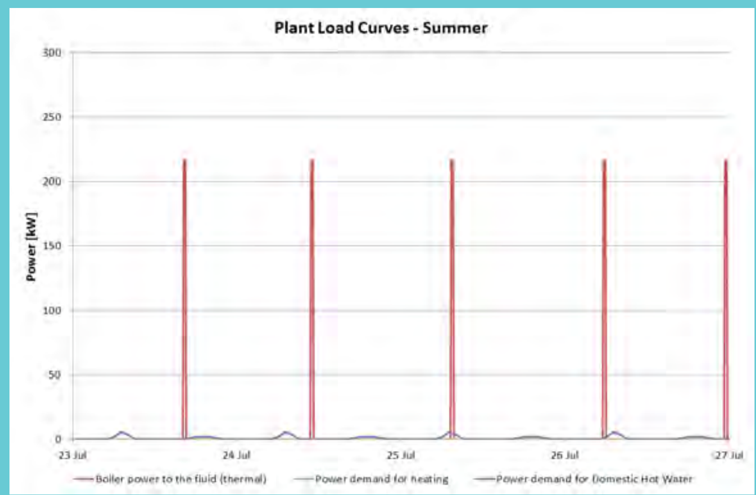


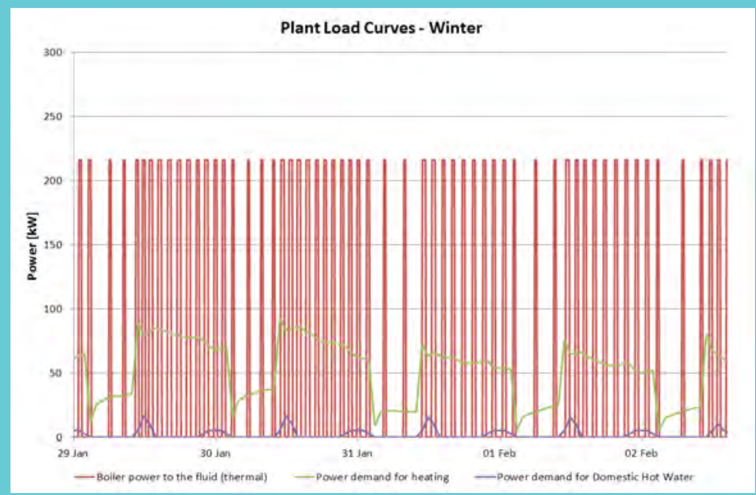




Plant Model - Load Curves







	Unit	Gas	Electricity	Total
Final Energy consumption	kWhFE/m²/y	313.3	49.2	362.5
Primary Energy consumption	kWhPE/m²/y	313.3	126.9	440.2
CO2 Emissions	kgCO2eq/m²/y	76.1	4.0	80.2

4.3. Paris - Case 1 bis: Good Envelope, No Control

Control: No Control

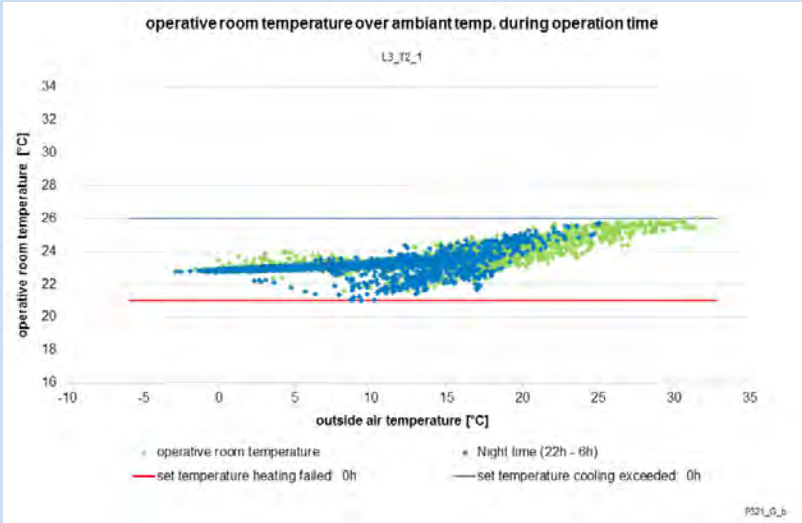
Envelope Perfomance: Good

Heating: Old Boiler - 1 speed burner

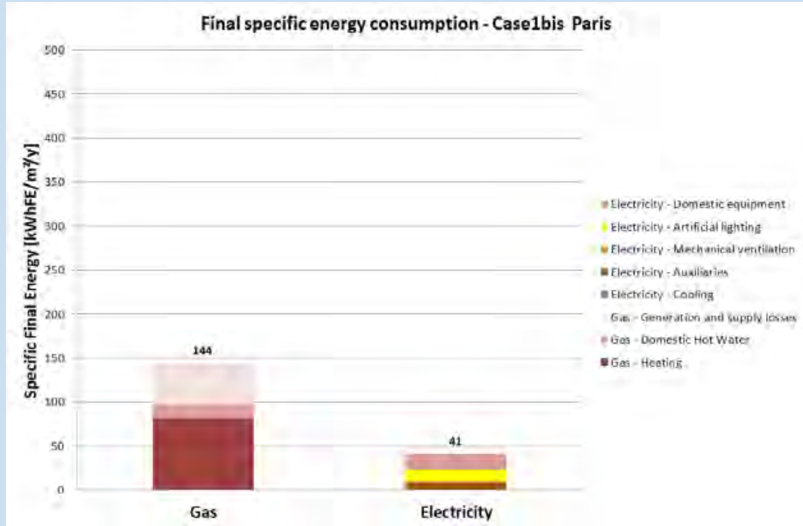
Cooling: Split unit for cooling (low efficiency)

Plant sized following the low envelope demand

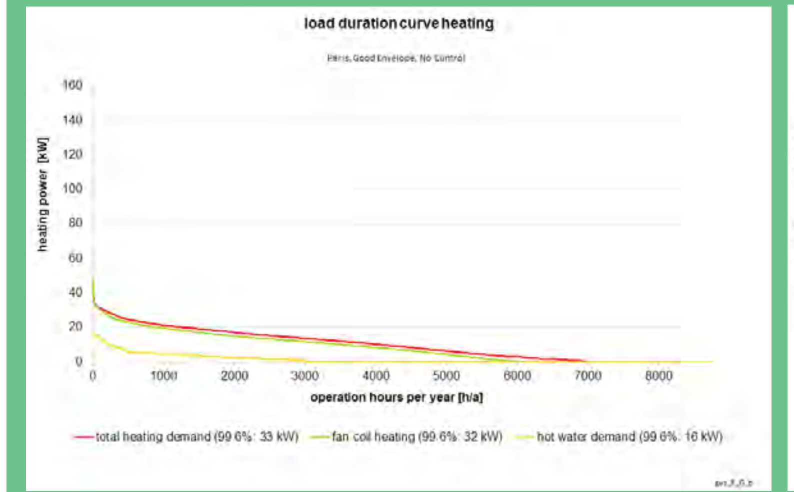
Comfort - Apartment L3_T2 (3rd floor, 2 rooms, SE-SW)

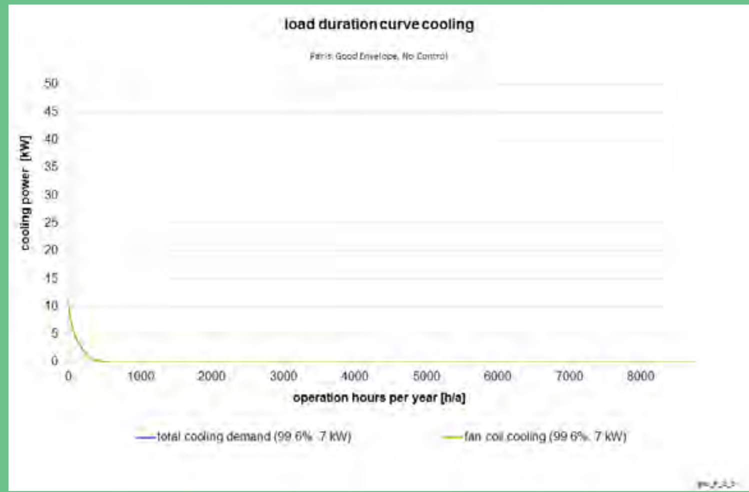


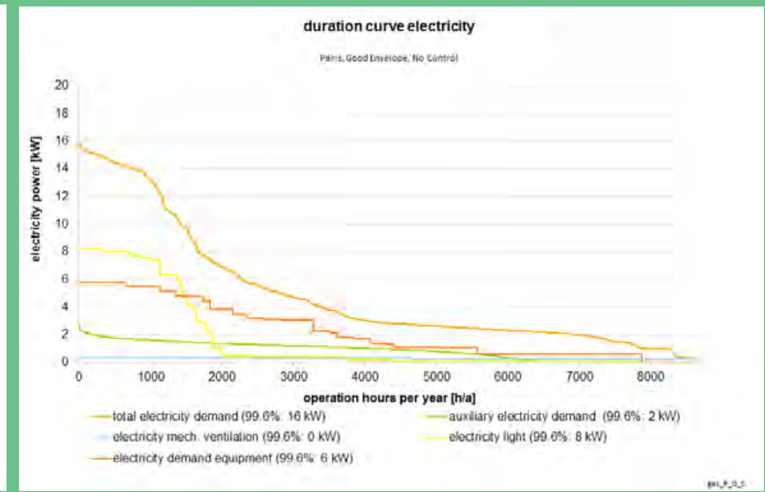
Final Specific Energy Consumption

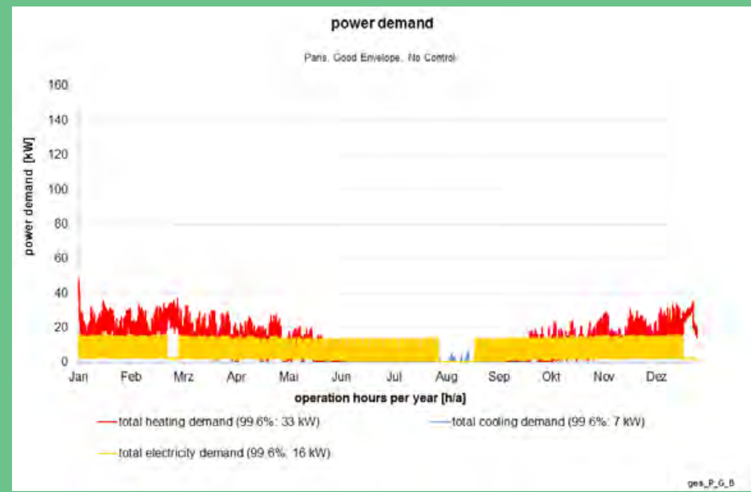


Energy Demand - Load Curves

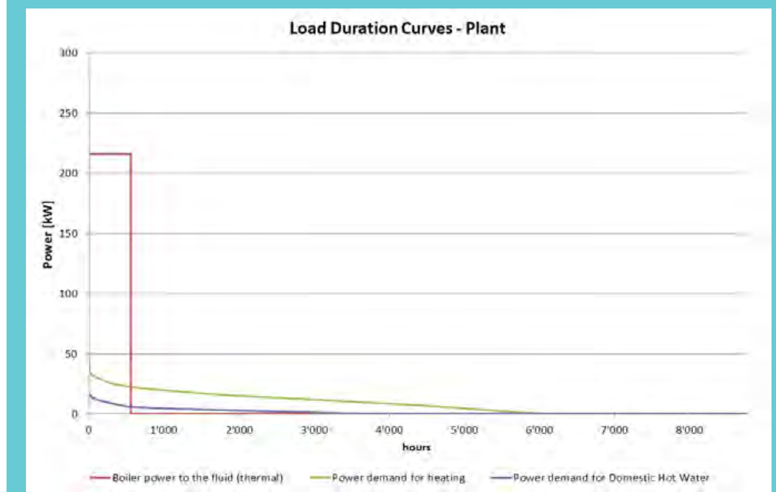


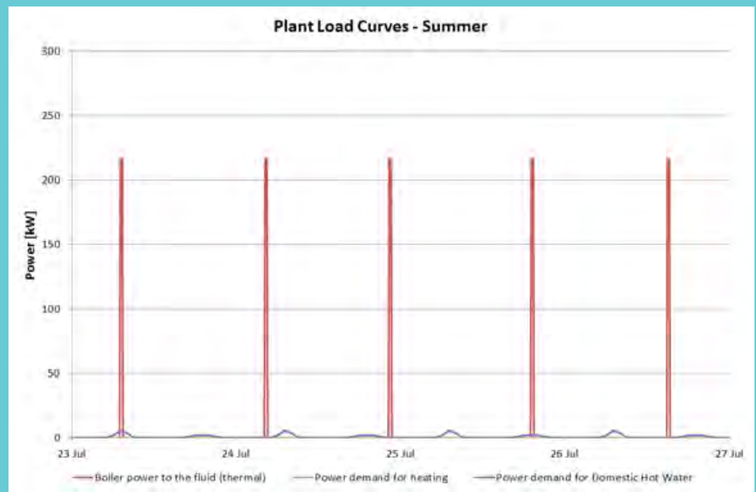


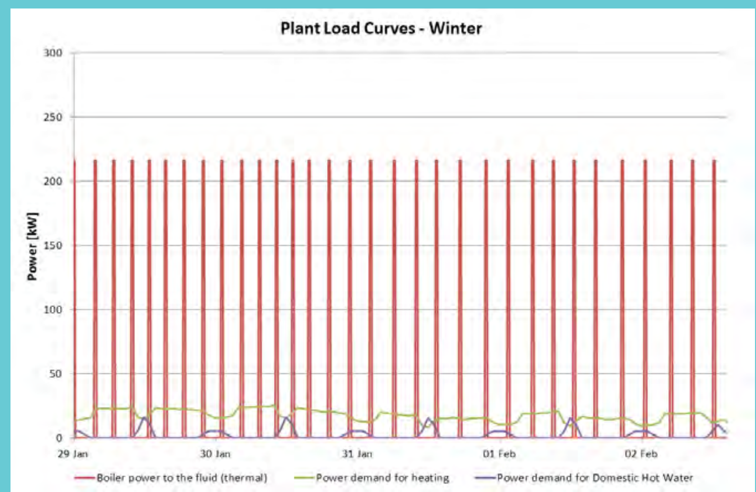




Plant Model - Load Curves







	Unit	Gas	Electricity	Total
Final Energy consumption	kWhFE/m²/y	144.0	41.2	185.3
Primary Energy consumption	kWhPE/m²/y	144.0	106.4	250.4
CO2 Emissions	kgCO2eq/m²/y	35.0	3.4	38.4

4.4. Paris - Case 1 ter: Low Envelope, Night Time Reduction

Control: Night time reduction

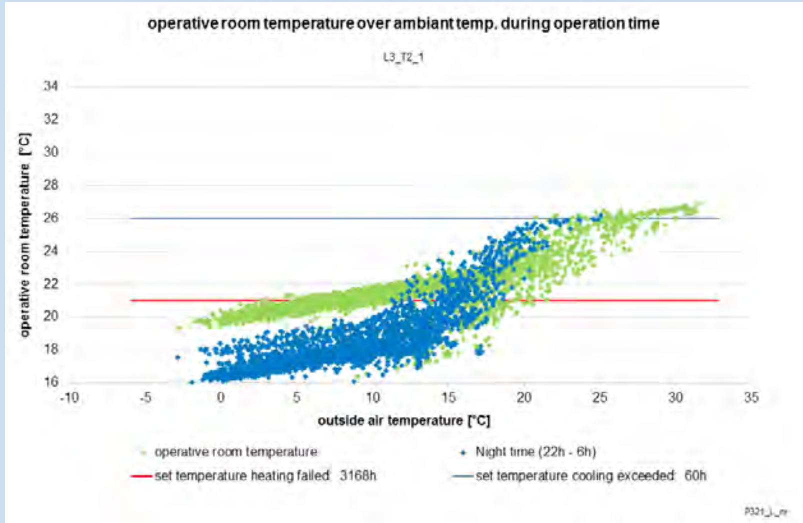
Envelope Performance : Low

Heating: New condensing boiler - modulating burner

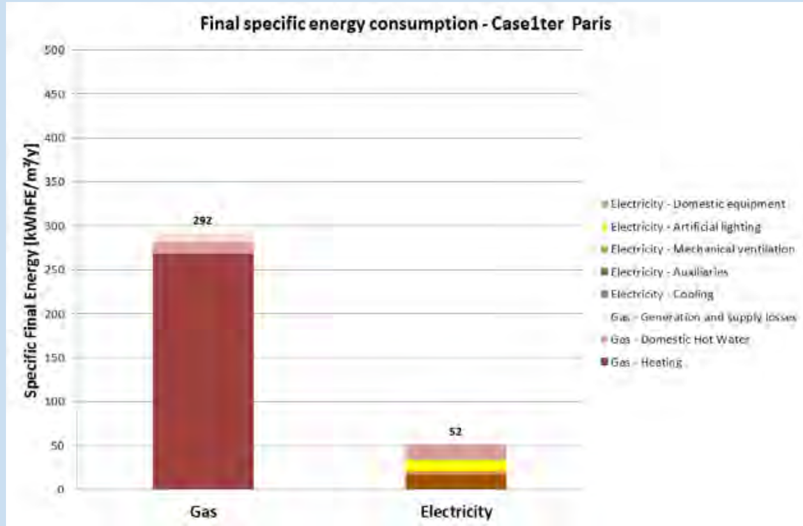
Cooling: Split unit for cooling (high efficiency)

Plant sized following the low envelope demand

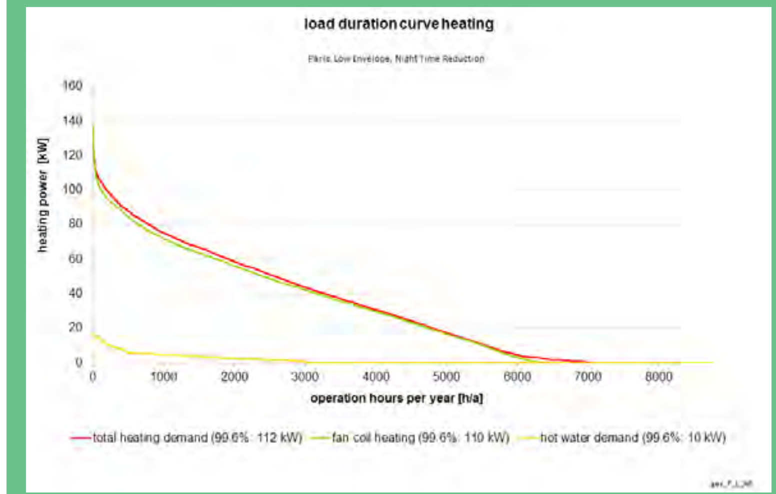
Comfort - Apartment L3_T2 (3rd floor, 2 rooms, SE-SW)

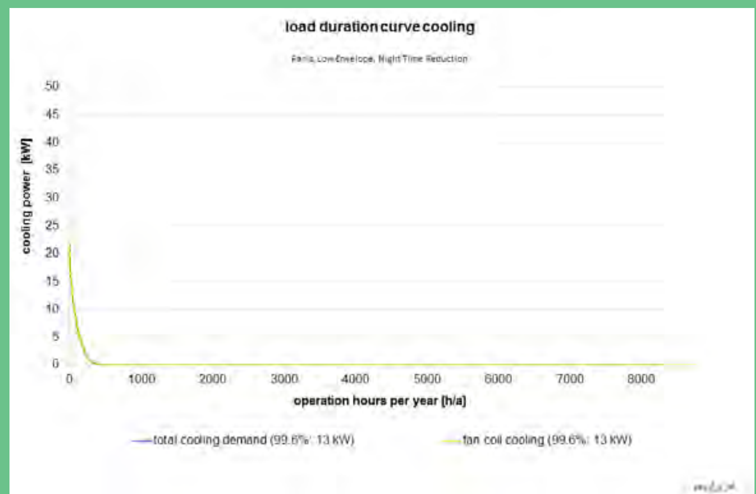


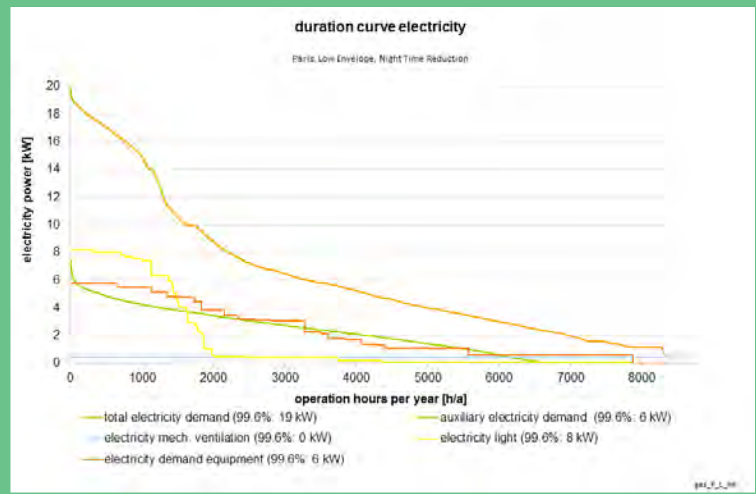
Final Specific Energy Consumption

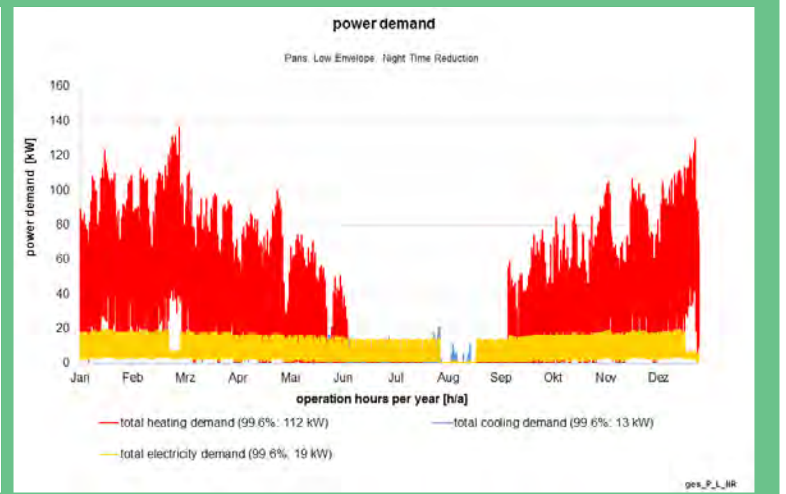


Energy Demand - Load Curves

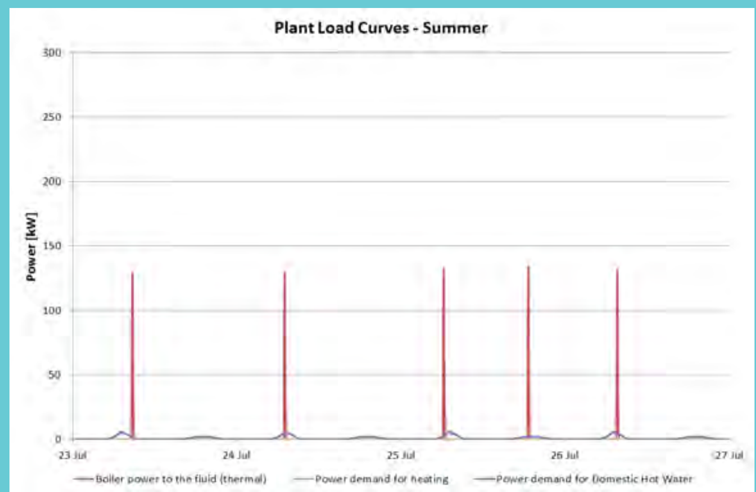


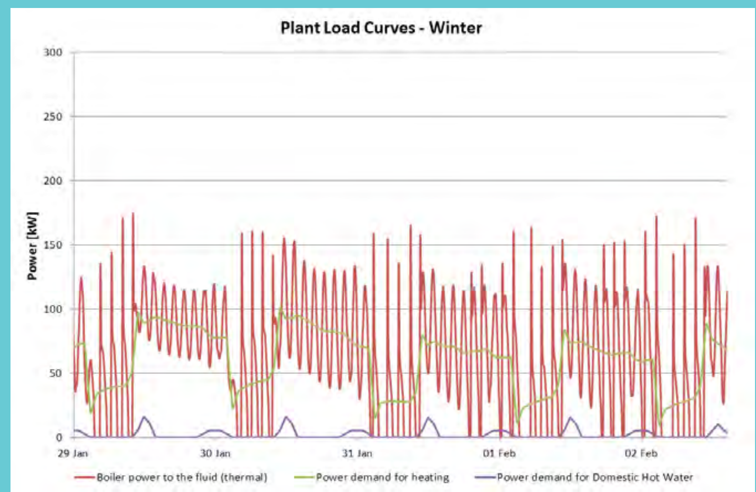






Plant Model - Load Curves





	Unit	Gas	Electricity	Total
Final Energy consumption	kWhFE/m²/y	291.7	51.7	343.3
Primary Energy consumption	kWhPE/m²/y	291.7	133.3	424.9
CO2 Emissions	kgCO2eq/m²/y	70.9	4.2	75.1

4.5. Paris - Case 1 ter HP: Low Envelope, Night Time Reduction with Heat Pump

Control: Night time reduction

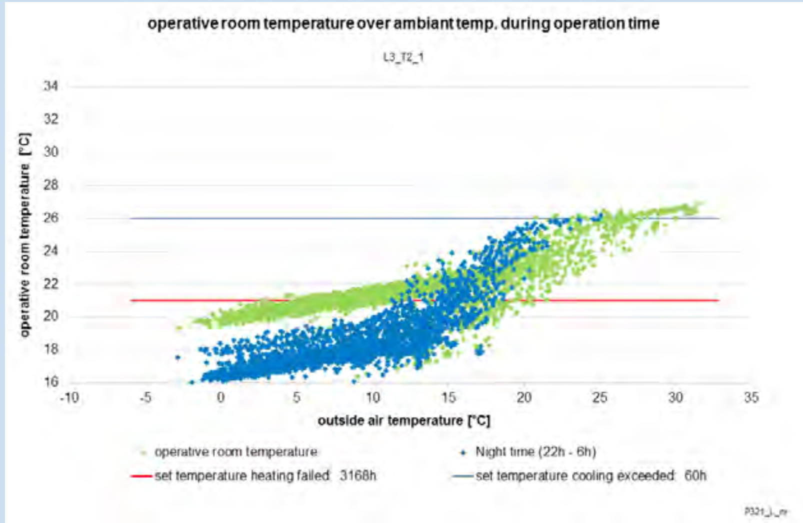
Envelope Performance : Low

Heating: Old boiler (for domestic hot water and outside temperature < 7°C), Heat pump

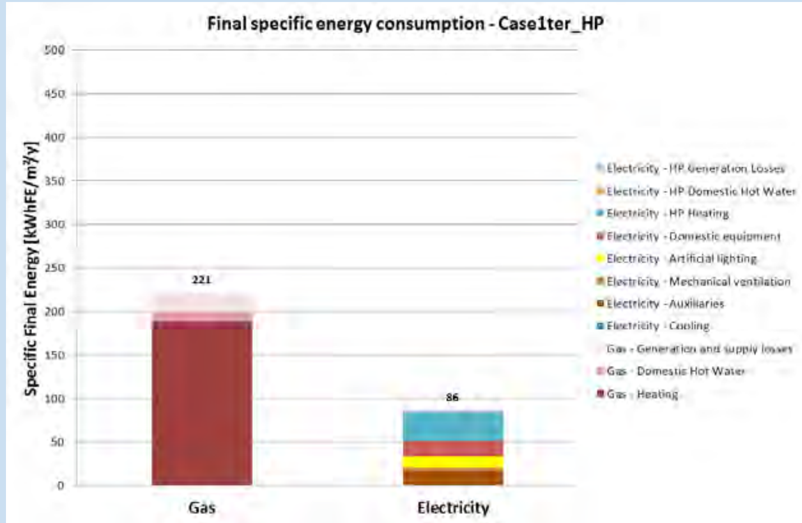
Cooling: Split unit for cooling (high efficiency)

Heat pump sized for T°C outside = 7°C

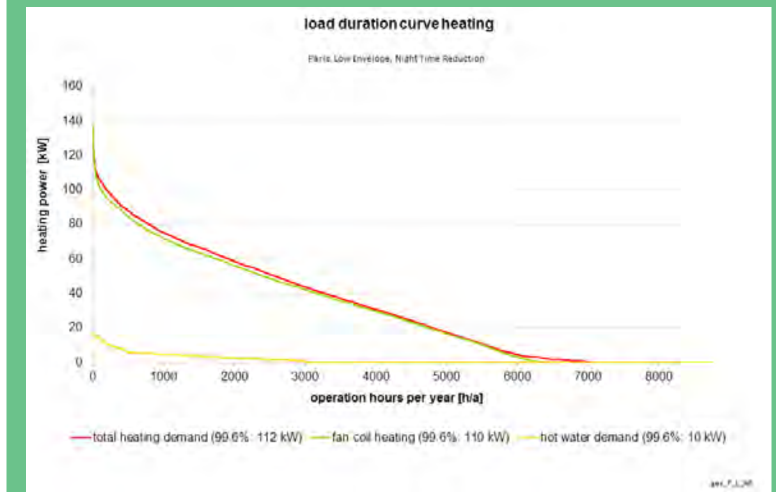
Comfort - Apartment L3_T2 (3rd floor, 2 rooms, SE-SW)

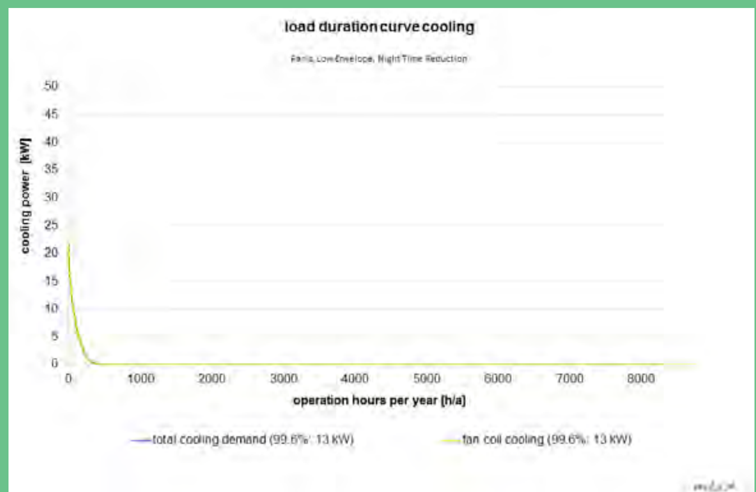


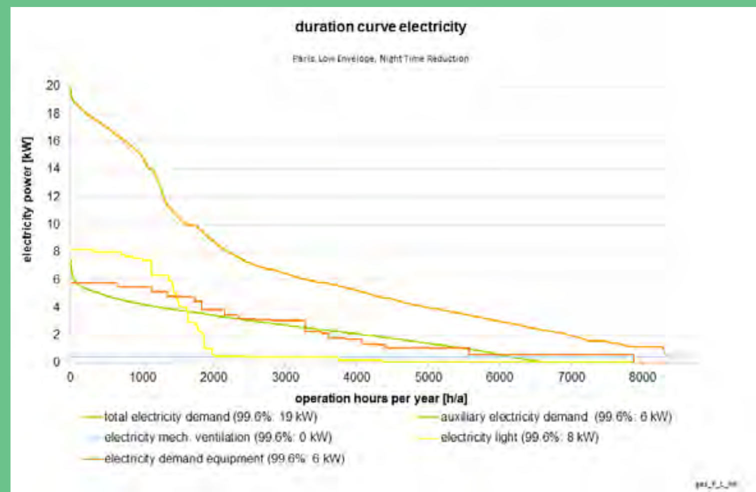
Final Specific Energy Consumption

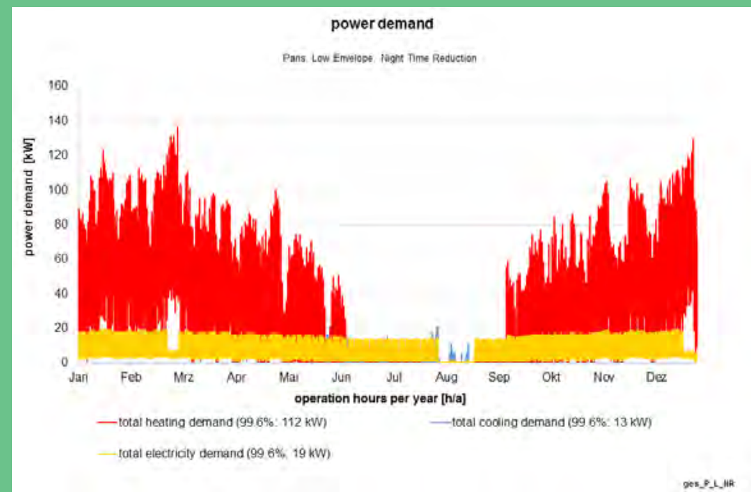


Energy Demand - Load Curves

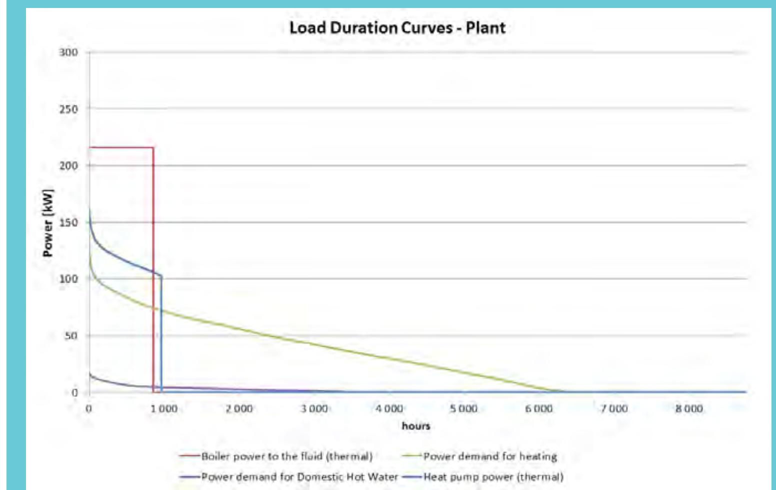


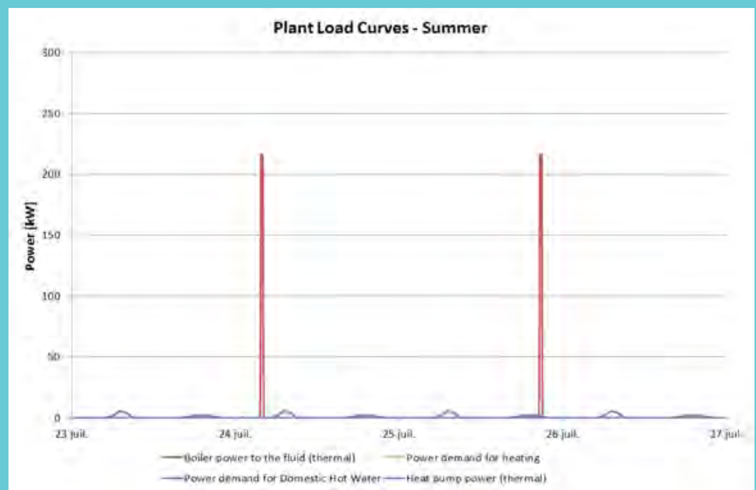


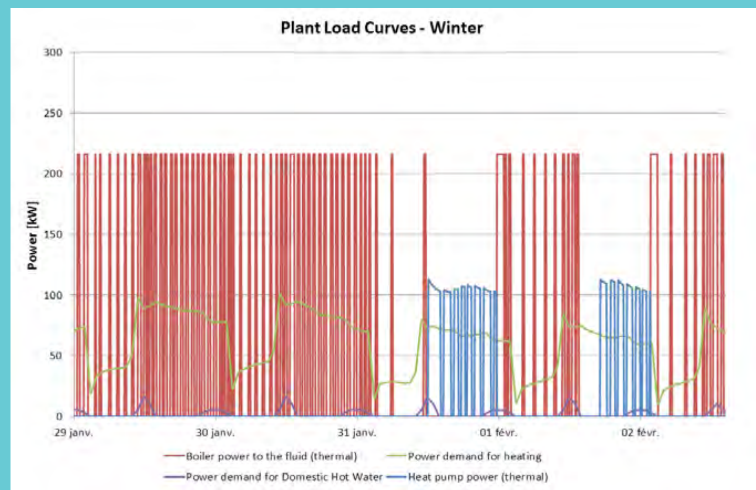




Plant Model - Load Curves







	Unit	Gas	Electricity	Total
Final Energy consumption	kWhFE/m²/y	221.0	86.4	**307.4**
Primary Energy consumption	kWhPE/m²/y	221.0	222.9	**443.9**
CO2 Emissions	kgCO2eq/m²/y	53.7	7.1	**60.8**

4.6. Paris - Case 2: Good Envelope, Night Time Reduction, Thermostat on Radiators

Control: Night Time Reduction, Thermostat on Radiators

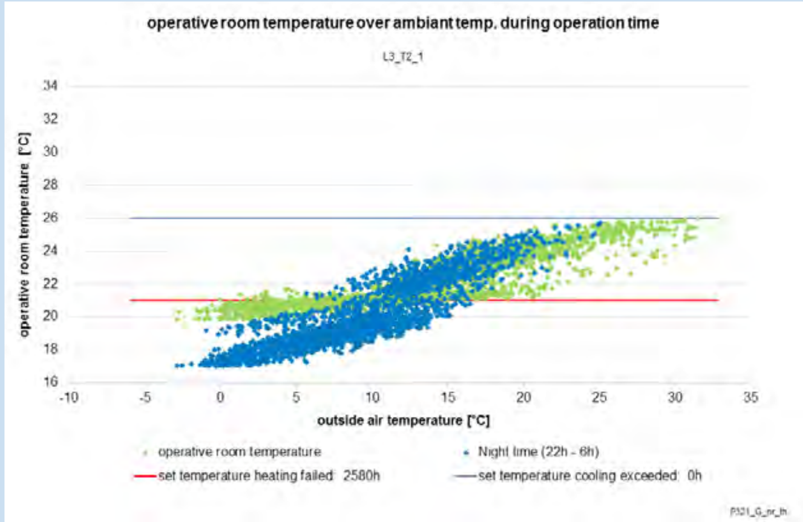
Envelope Perfomance: Good

Heating: New condensing boiler - modulating burner

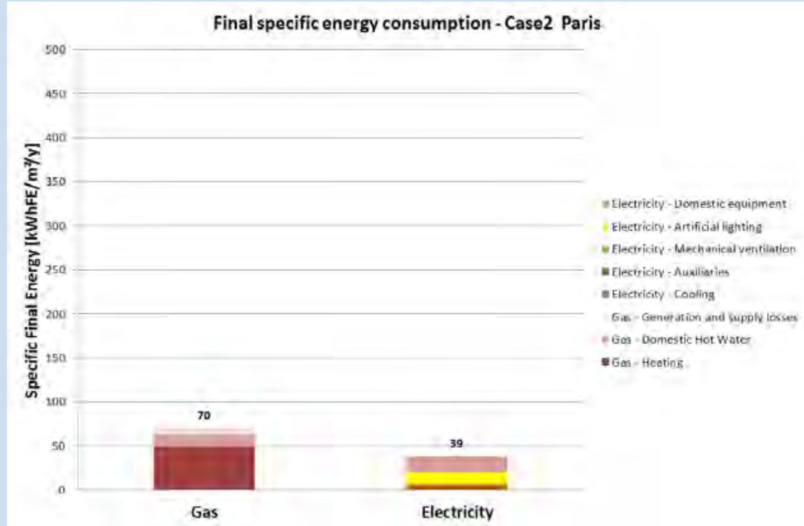
Cooling: Split unit for cooling (high efficiency)

Plant sized following the good envelope demand

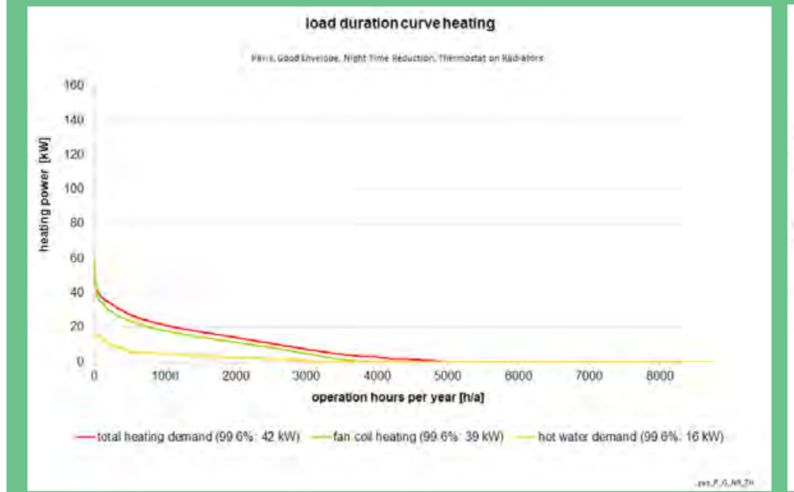
Comfort - Apartment L3_T2 (3rd floor, 2 rooms, SE-SW)

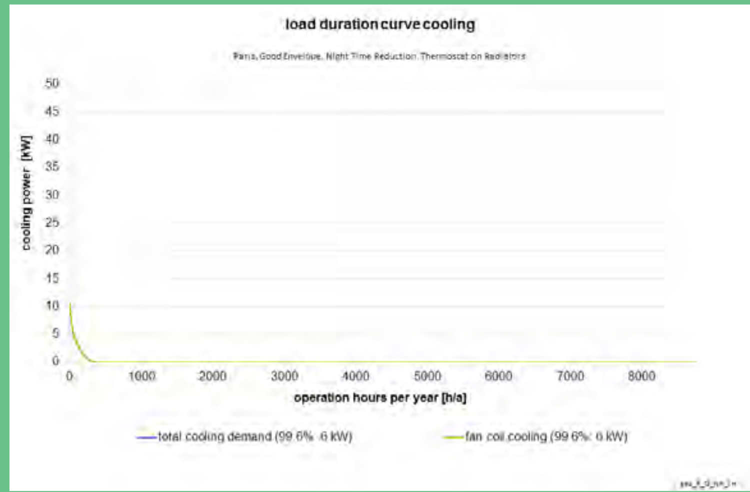


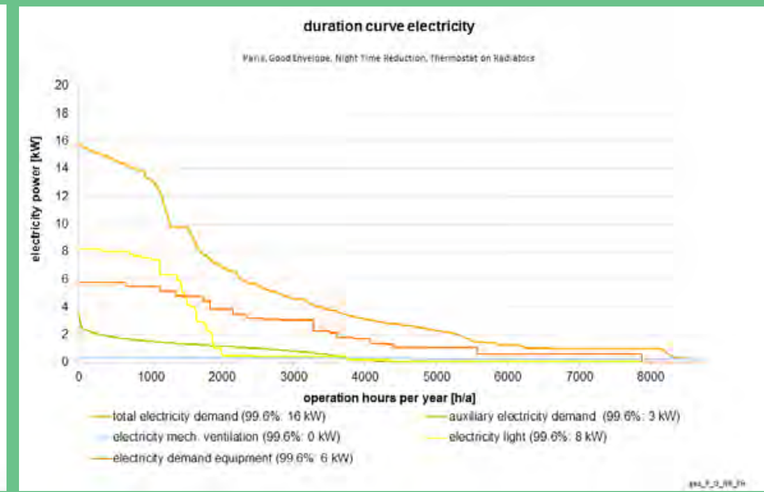
Final Specific Energy Consumption

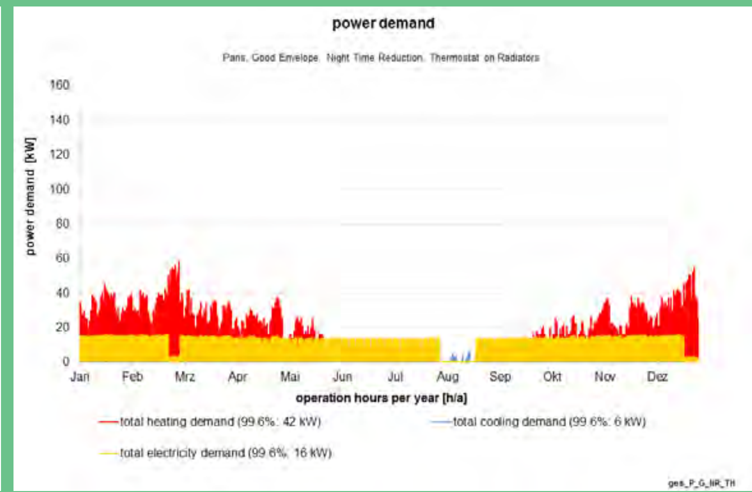


Energy Demand - Load Curves

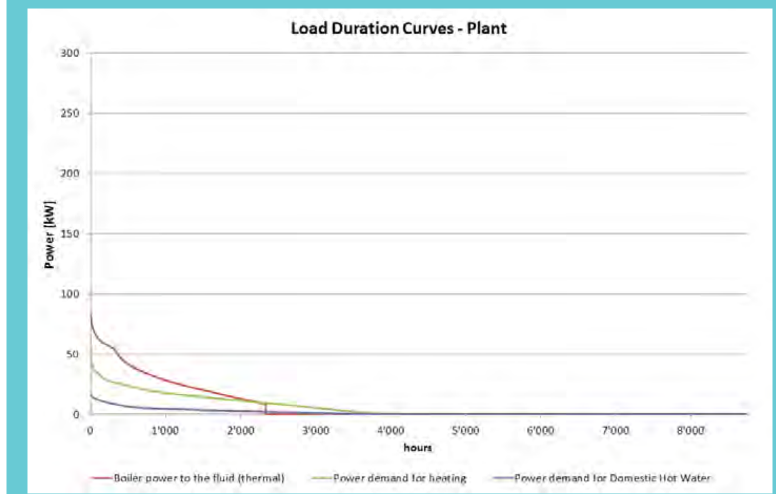


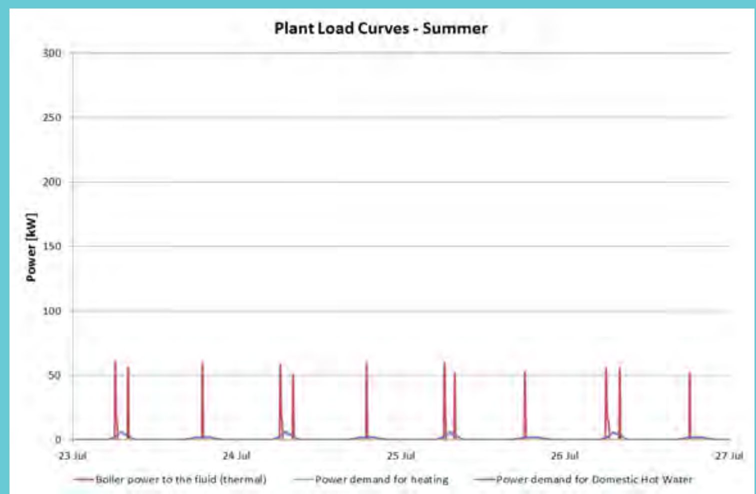


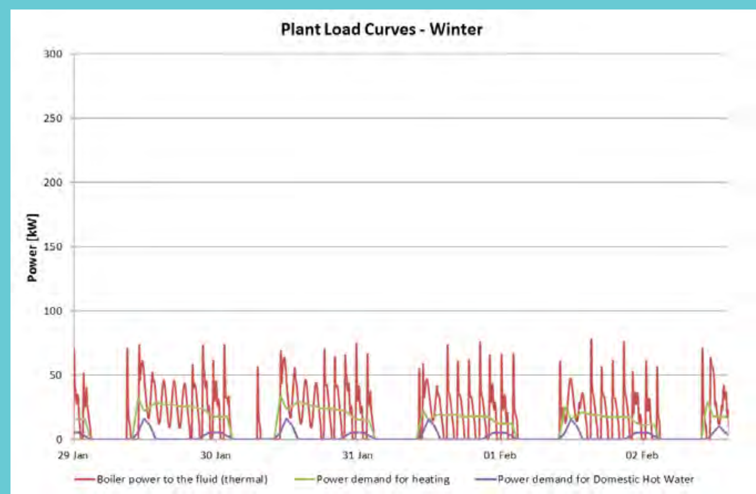




Plant Model - Load Curves







	Unit	Gas	Electricity	Total
Final Energy consumption	kWhFE/m²/y	70.1	38.5	108.7
Primary Energy consumption	kWhPE/m²/y	70.1	99.4	169.6
CO2 Emissions	kgCO2eq/m²/y	17.0	3.2	20.2

4.7. Paris - Case 2 HP: Good Envelope, Night Time Reduction, Thermostat on Radiators, Heat Pump

Control: Night Time Reduction, Thermostat on Radiators

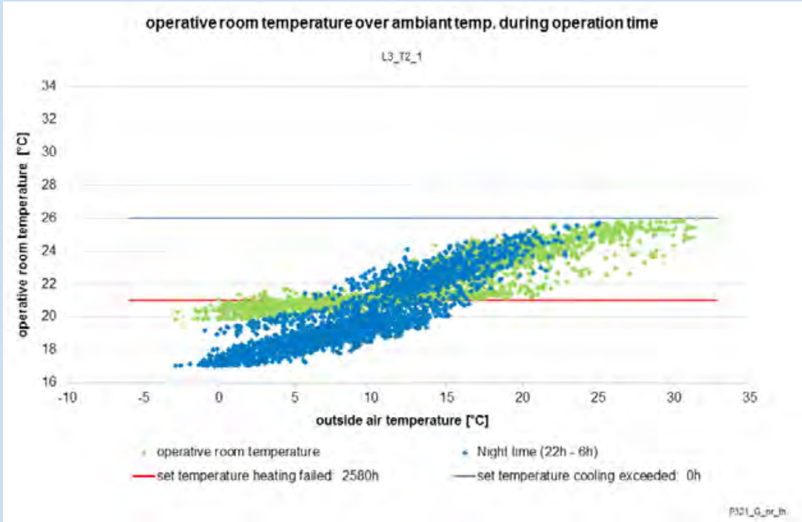
Envelope Perfomance: Good

Heating and Domestic Hot Water: 2 separate Heat Pumps

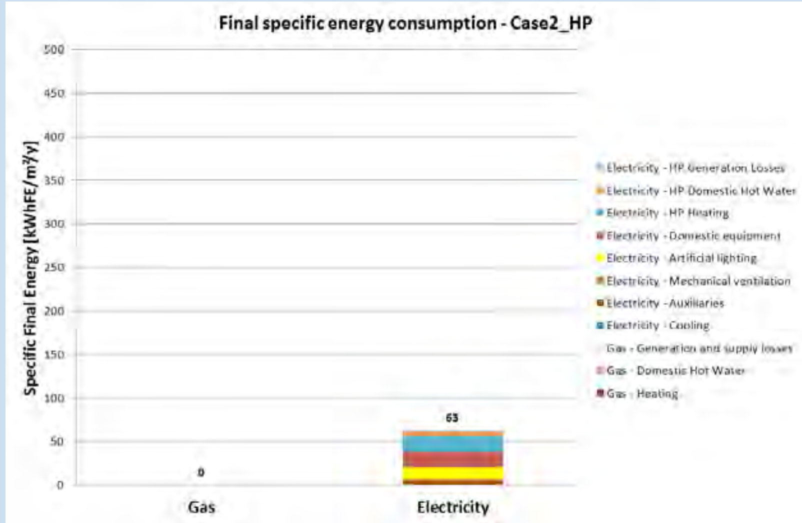
Cooling: Split unit for cooling (high efficiency)

Plant sized following the good envelope demand

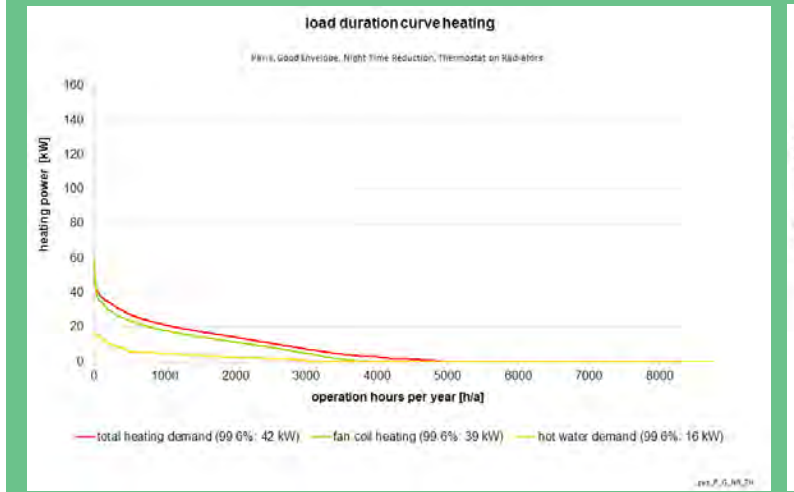
Comfort - Apartment L3_T2 (3rd floor, 2 rooms, SE-SW)

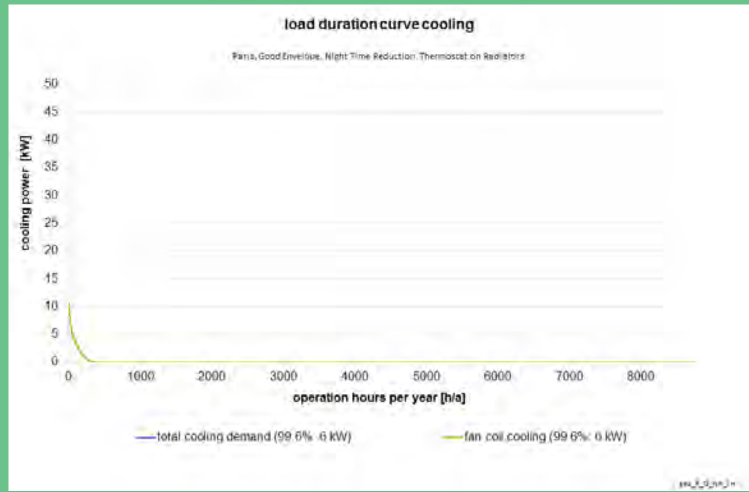


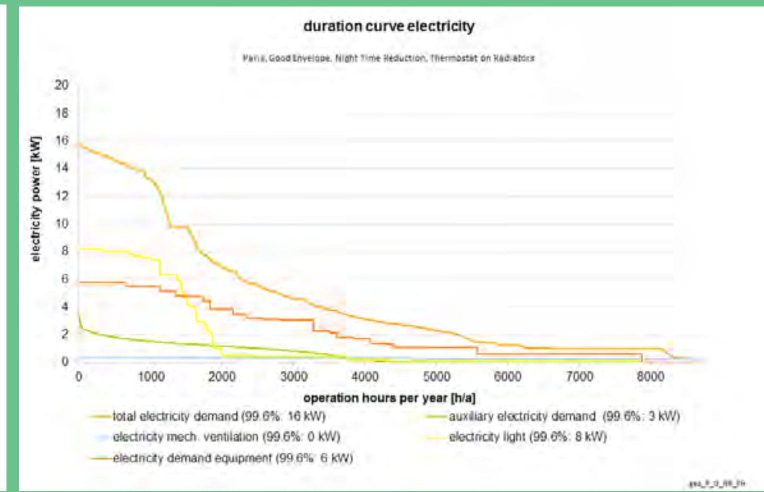
Final Specific Energy Consumption

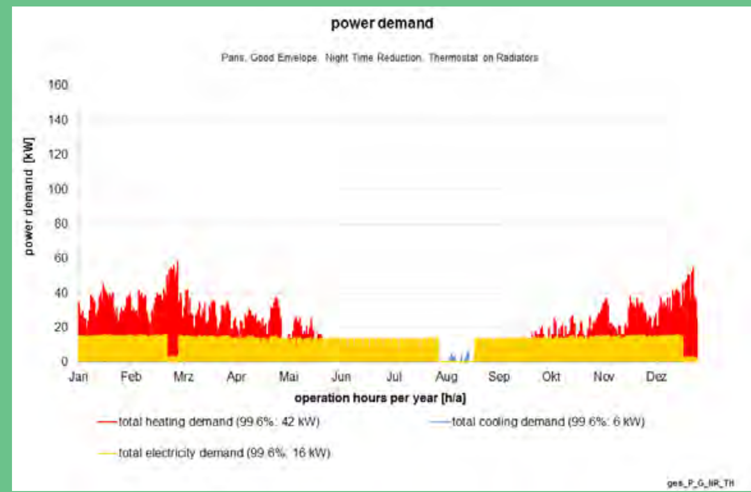


Energy Demand - Load Curves

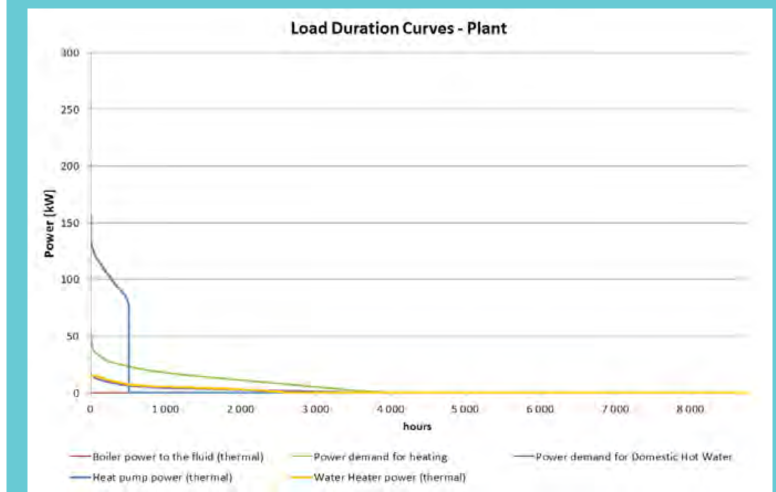


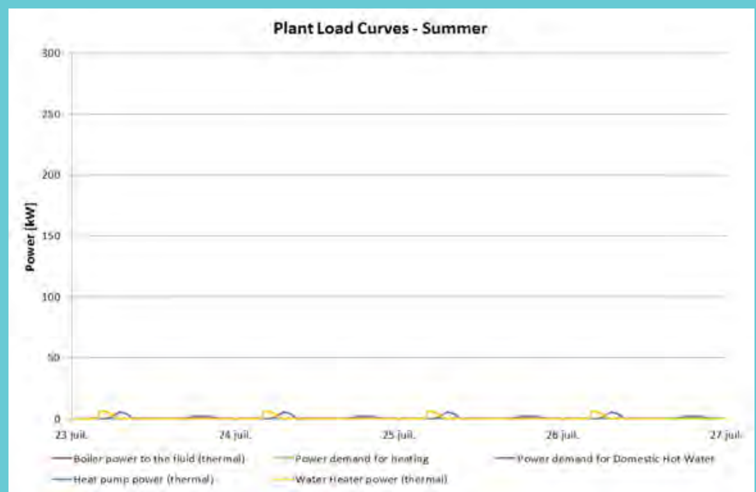


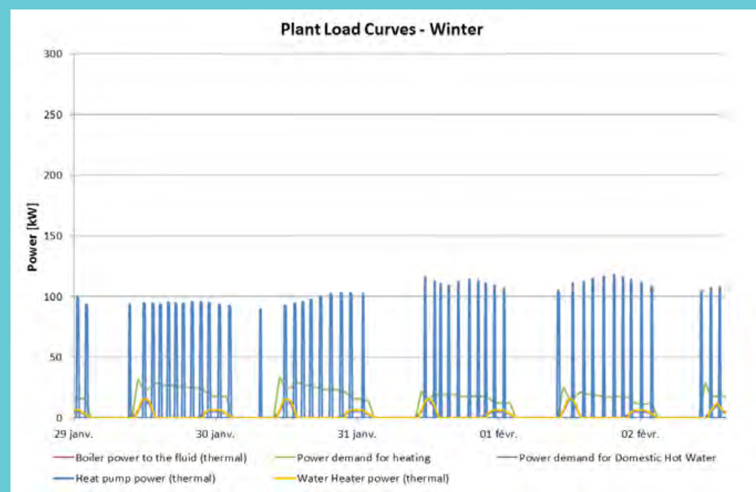




Plant Model - Load Curves







	Unit	Gas	Electricity	Total
Final Energy consumption	kWhFE/m²/y	70.1	38.5	108.7
Primary Energy consumption	kWhPE/m²/y	70.1	99.4	169.6
CO2 Emissions	kgCO2eq/m²/y	17.0	3.2	20.2

4.8. Paris - Case 2 bis: Good Envelope, Night Time Reduction

Control: Night Time Reduction

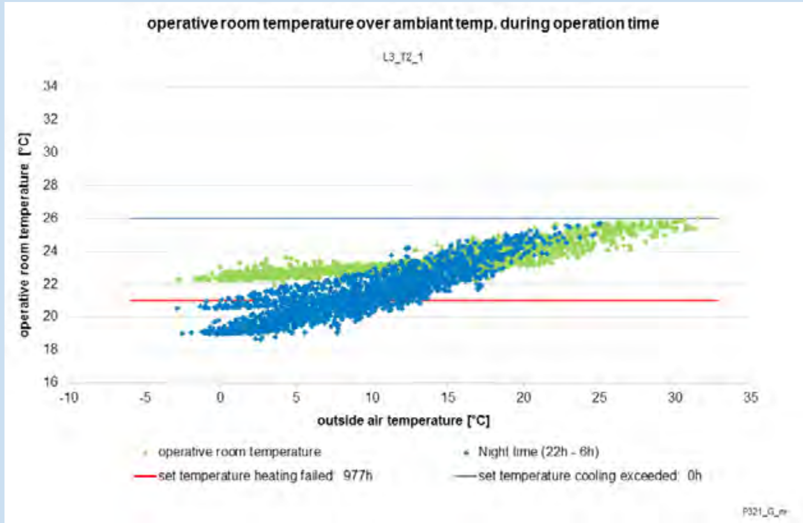
Envelope Perfomance: Good

Heating: New condensing boiler - modulating burner

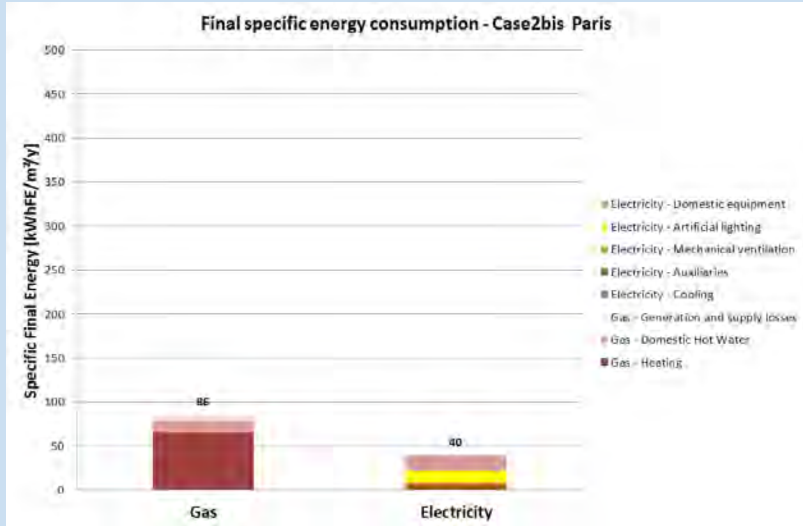
Cooling: Split unit for cooling (high efficiency)

Plant sized following the good envelope demand

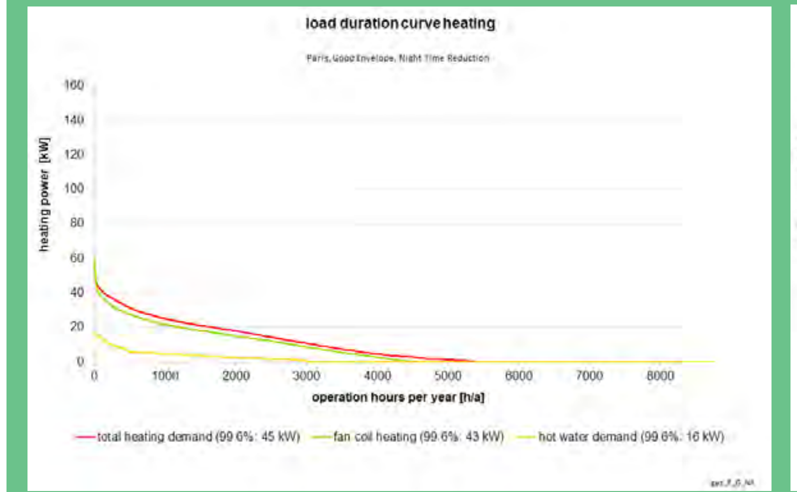
Comfort - Apartment L3_T2 (3rd floor, 2 rooms, SE-SW)

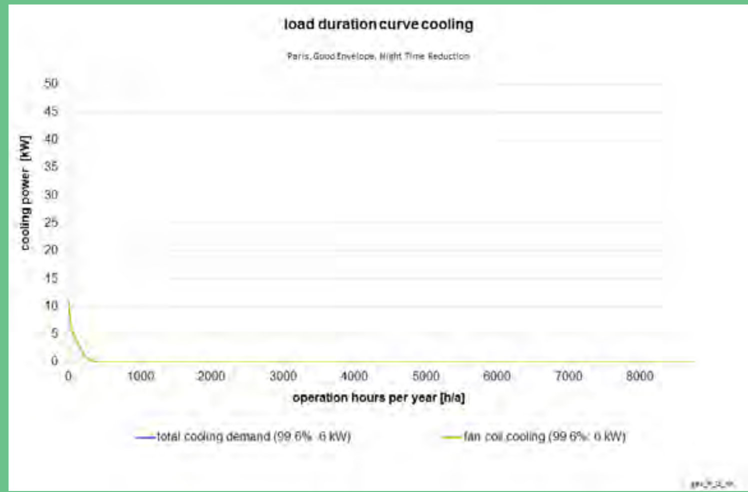


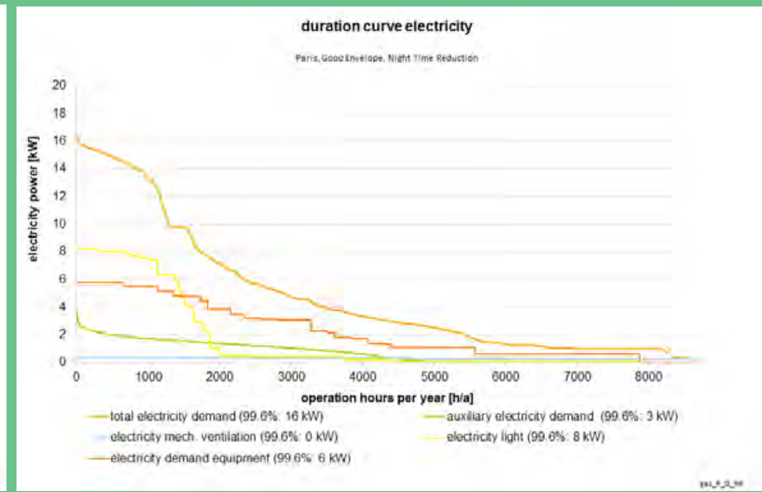
Final Specific Energy Consumption

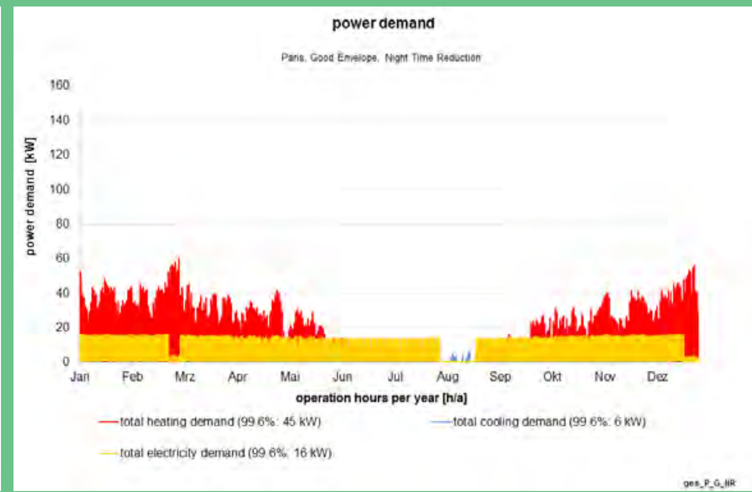


Energy Demand - Load Curves

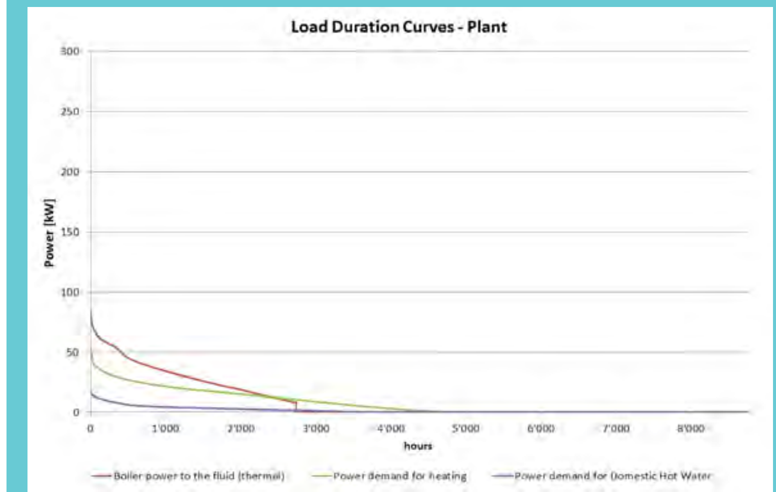


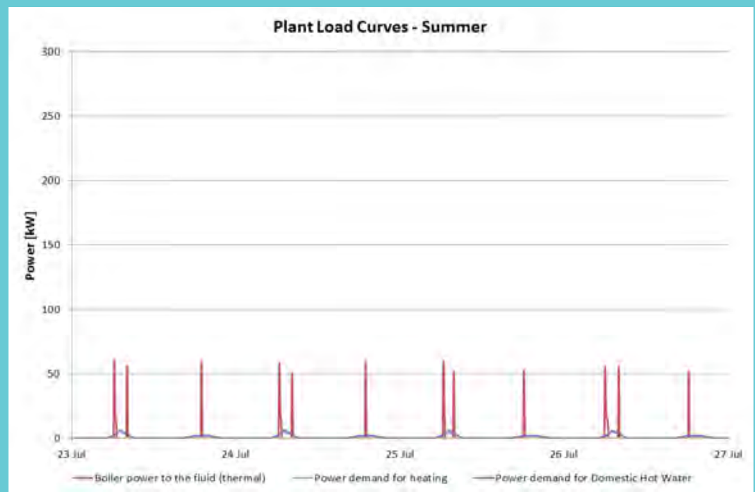


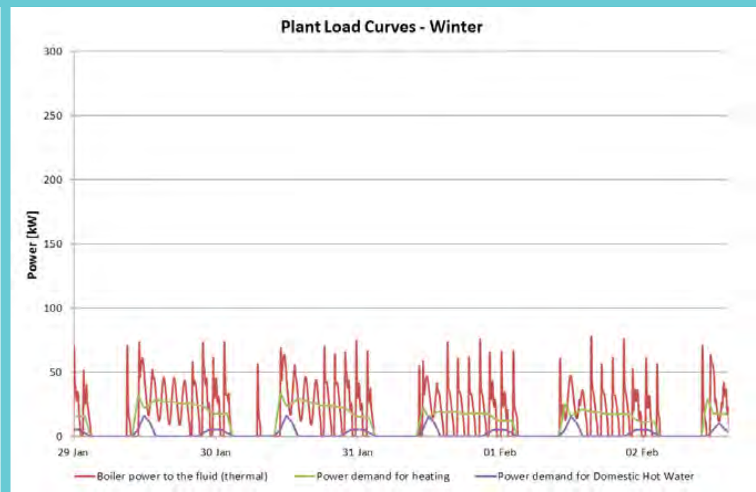




Plant Model - Load Curves







	Unit	Gas	Electricity	Total
Final Energy consumption	kWhFE/m²/y	85.8	39.7	125.4
Primary Energy consumption	kWhPE/m²/y	85.8	102.3	188.1
CO2 Emissions	kgCO2eq/m²/y	20.8	3.3	24.1

4. **Annex I: Detailed Results**

4.9. Paris - Case 2 ter : Good Envelope, Night Time Reduction, Thermostat on Radiators

Control: Night Time Reduction, Thermostat on Radiators

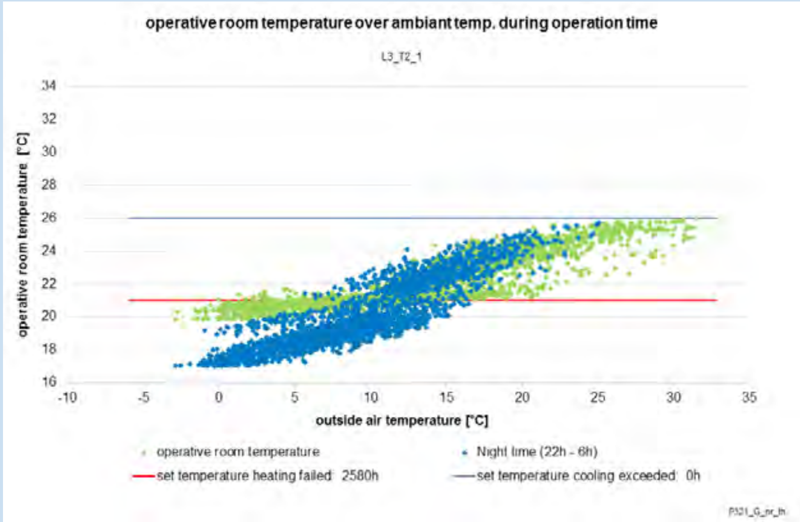
Envelope Perfomance: Good

Heating: New condensing boiler - modulating burner

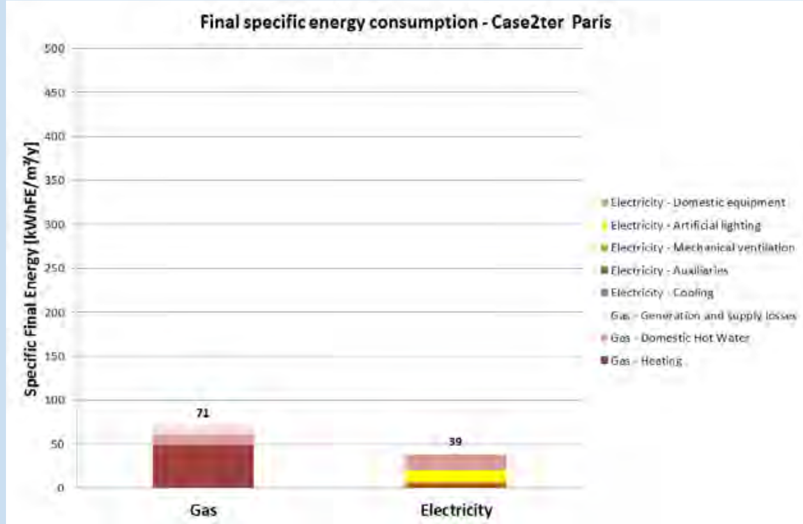
Cooling: Split unit for cooling (high efficiency)

Plant sized following the low envelope demand

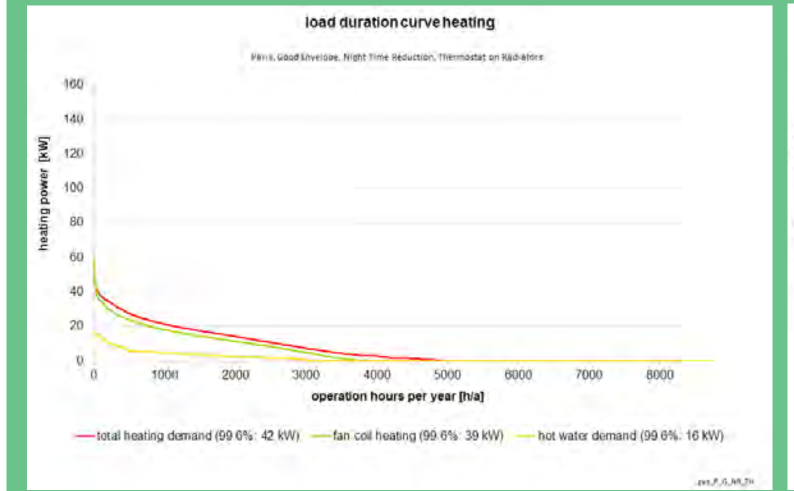
Comfort - Apartment L3_T2 (3rd floor, 2 rooms, SE-SW)

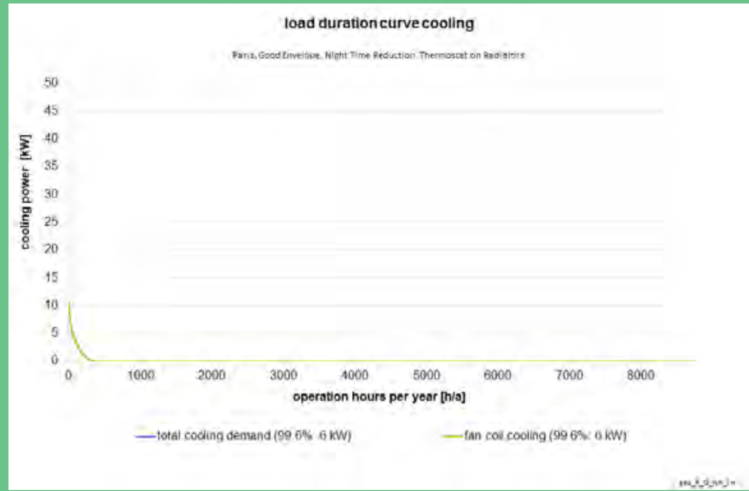


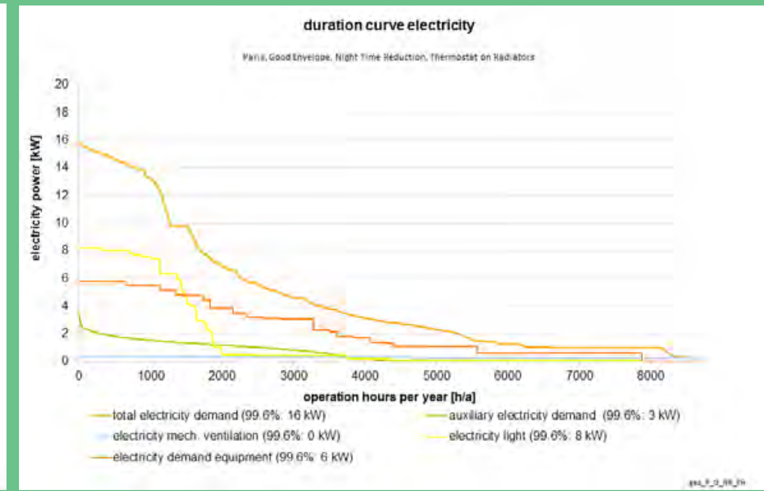
Final Specific Energy Consumption

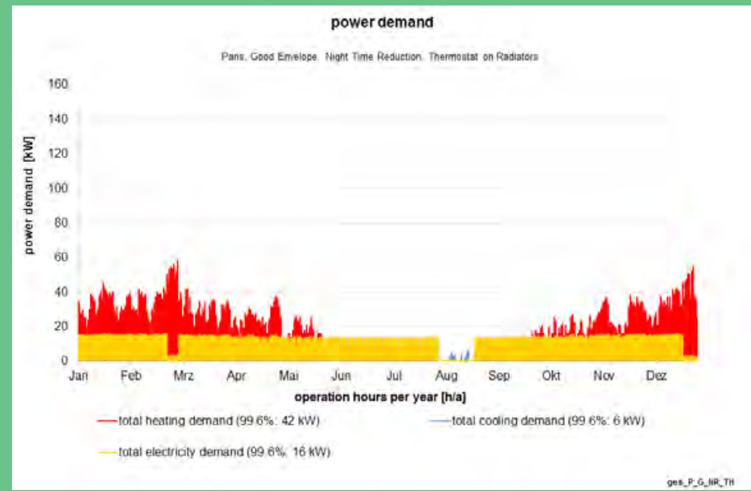


Energy Demand - Load Curves

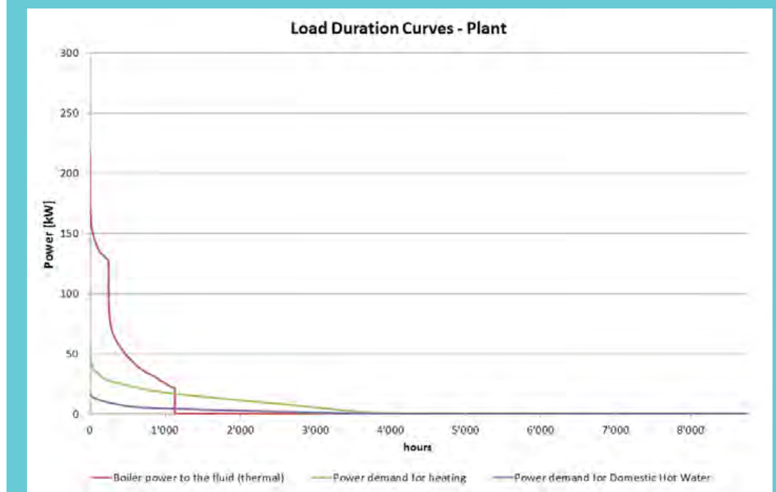


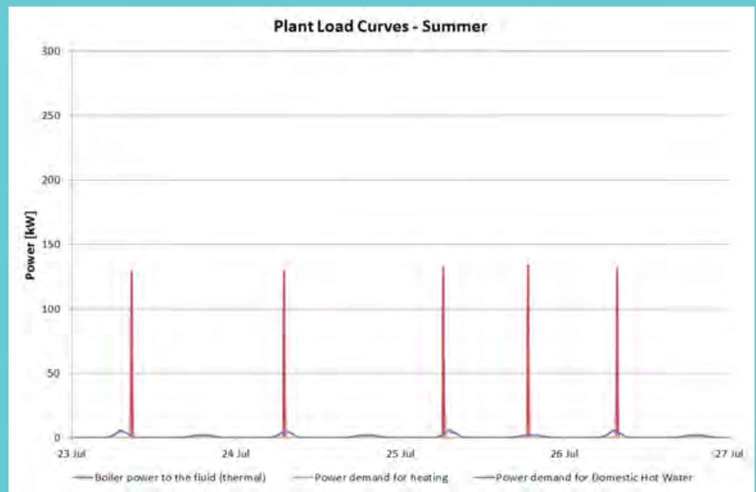


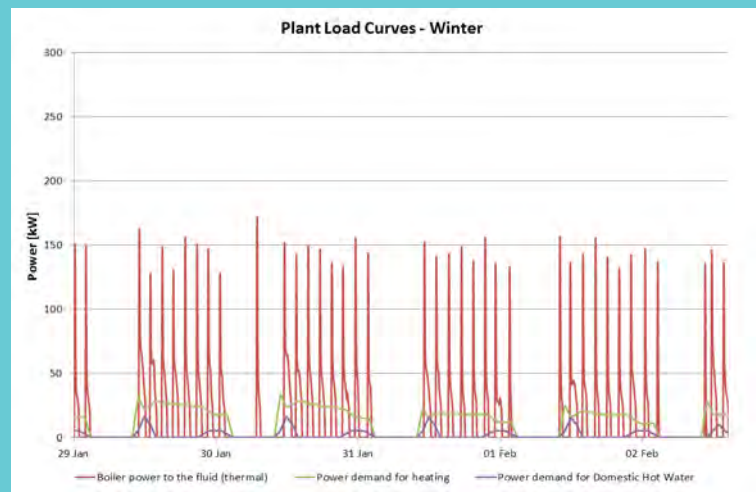




Plant Model - Load Curves







	Unit	Gas	Electricity	Total
Final Energy consumption	kWhFE/m²/y	0.0	63.0	**63.0**
Primary Energy consumption	kWhPE/m²/y	0.0	162.6	**162.6**
CO2 Emissions	kgCO2eq/m²/y	0.0	5.2	**5.2**

4. **Annex I: Detailed Results**

4.10. Paris - Case 2 ter HP : Good Envelope, Night Time Reduction, Thermostat on Radiators, Heat Pump

Control: Night Time Reduction, Thermostat on Radiators

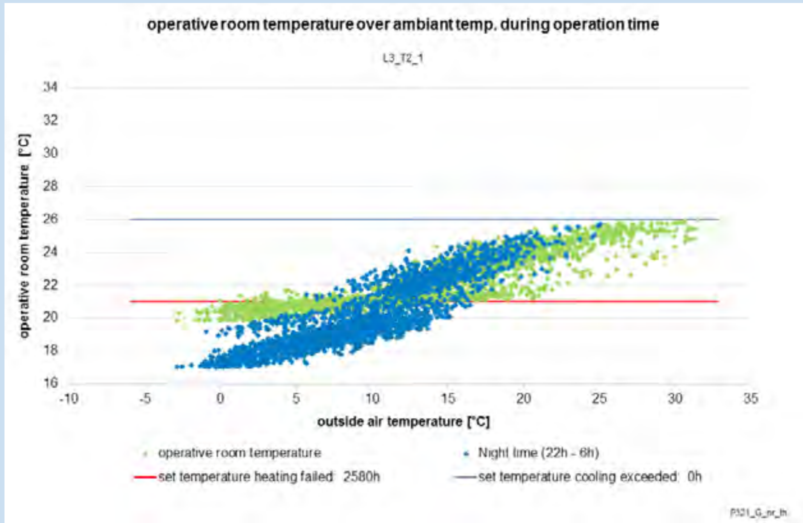
Envelope Perfomance: Good

Heating: Heat Pump

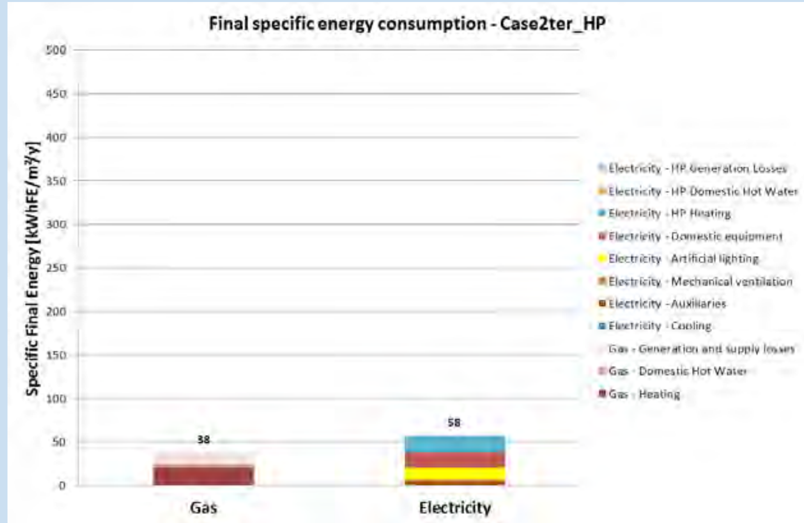
Domestic Hot Water: old boiler

Cooling: Split unit for cooling (high efficiency)

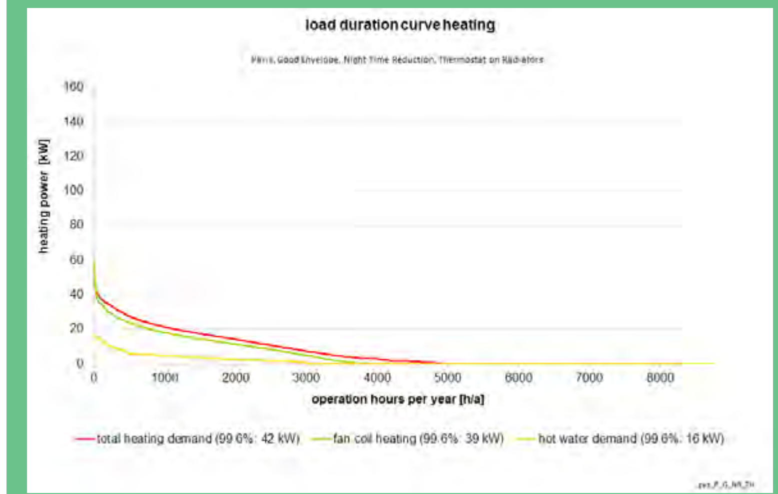
Comfort - Apartment L3_T2 (3rd floor, 2 rooms, SE-SW)

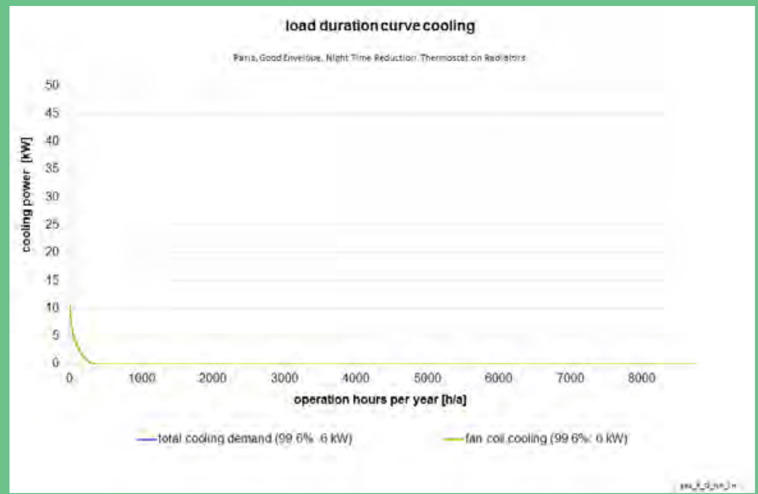


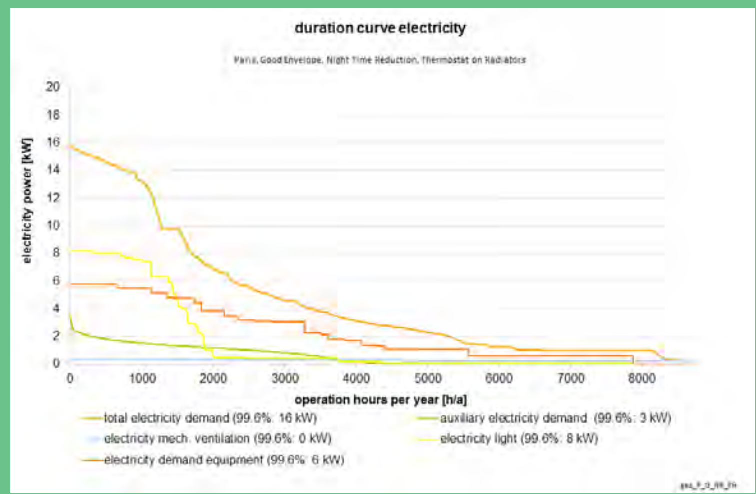
Final Specific Energy Consumption

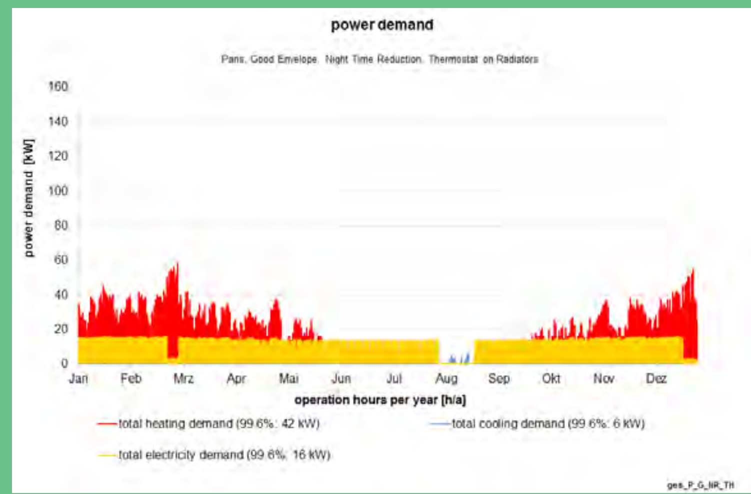


Energy Demand - Load Curves

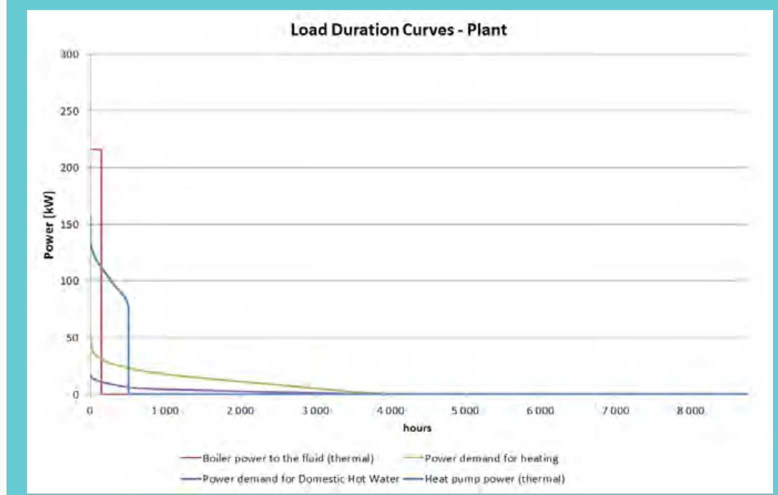


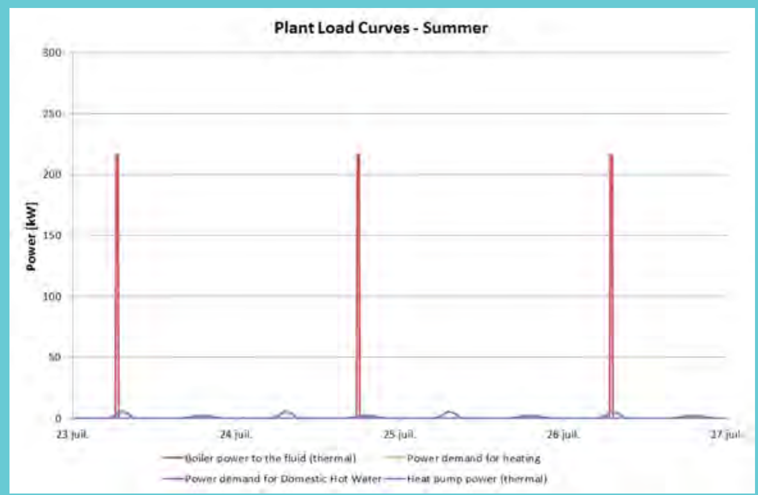






Plant Model - Load Curves





	Unit	Gas	Electricity	Total
Final Energy consumption	kWhFE/m²/y	38.1	57.8	**96.0**
Primary Energy consumption	kWhPE/m²/y	38.1	149.2	**187.3**
CO2 Emissions	kgCO2eq/m²/y	9.3	4.7	**14.0**

4.11. Paris - Case 3: Excellent Envelope Performance, Night Time Reduction, Thermostat on Radiators

Control: Night Time Reduction, Thermostat on Radiators

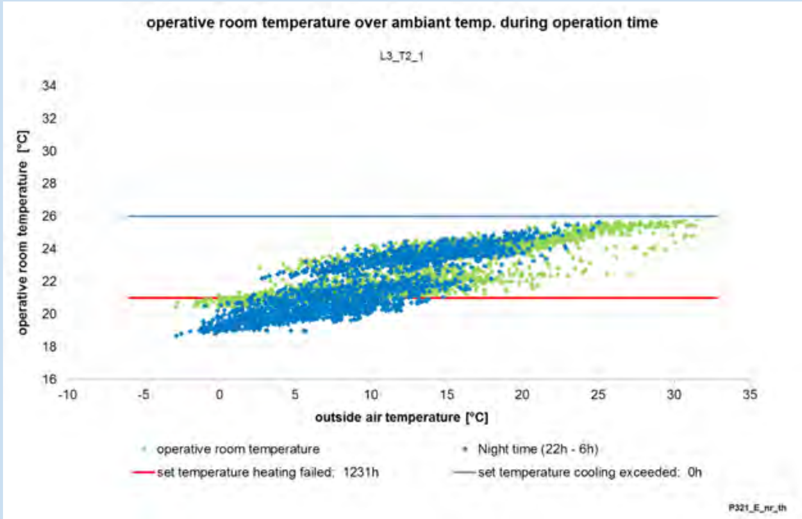
Envelope Perfomance: Excellent

Heating: New condensing boiler - modulating burner

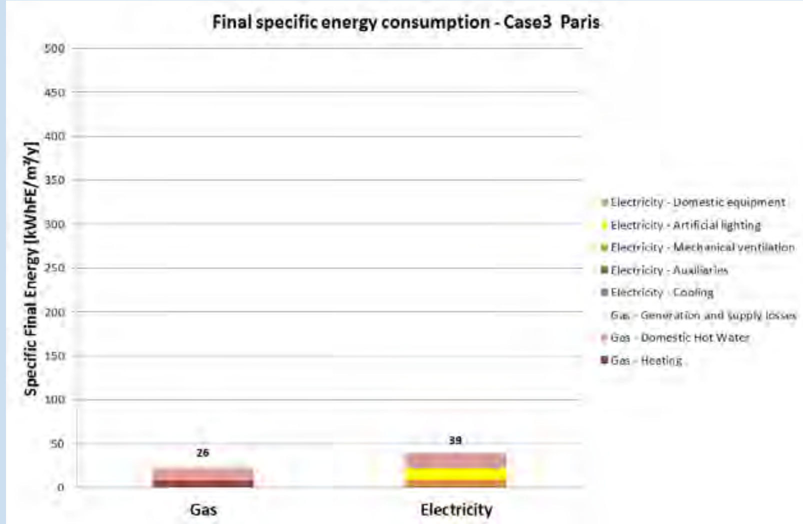
Cooling: Split unit for cooling (high efficiency)

Plant sized following the excellent envelope demand

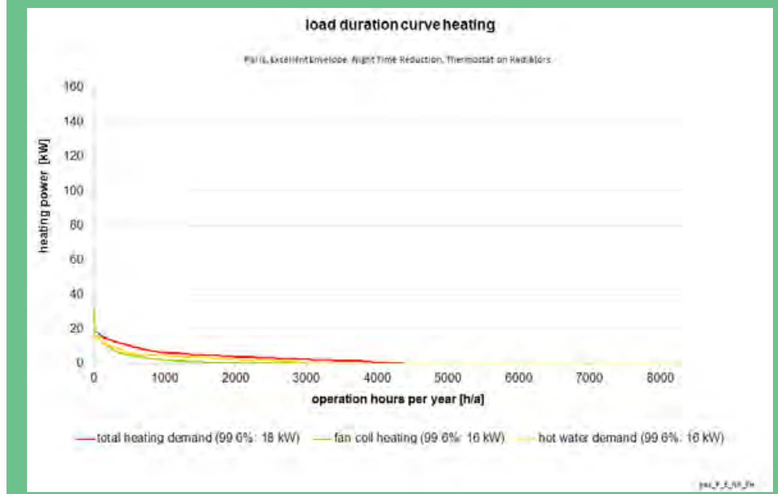
Comfort - Apartment L3_T2 (3rd floor, 2 rooms, SE-SW)

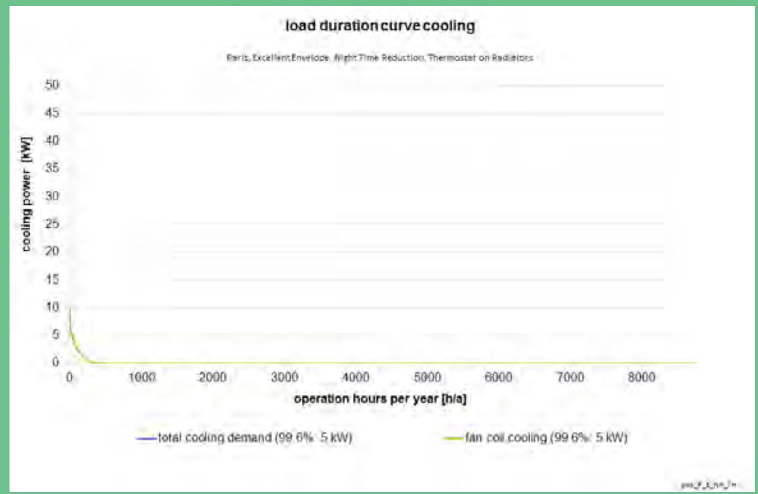


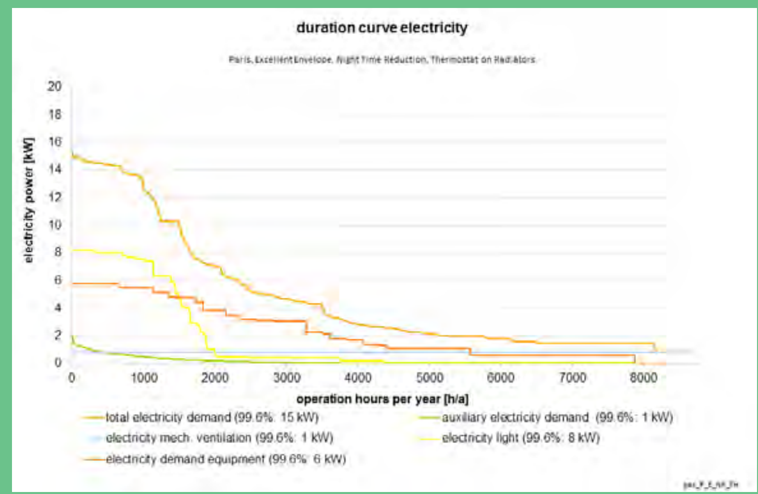
Final Specific Energy Consumption

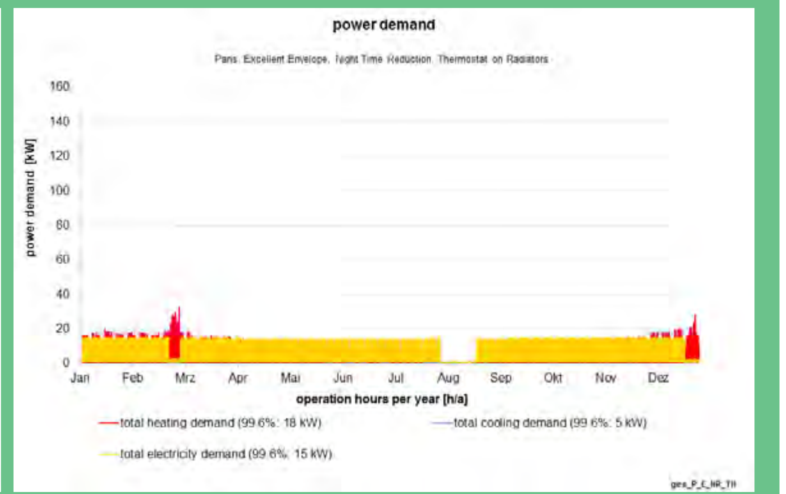


Energy Demand - Load Curves

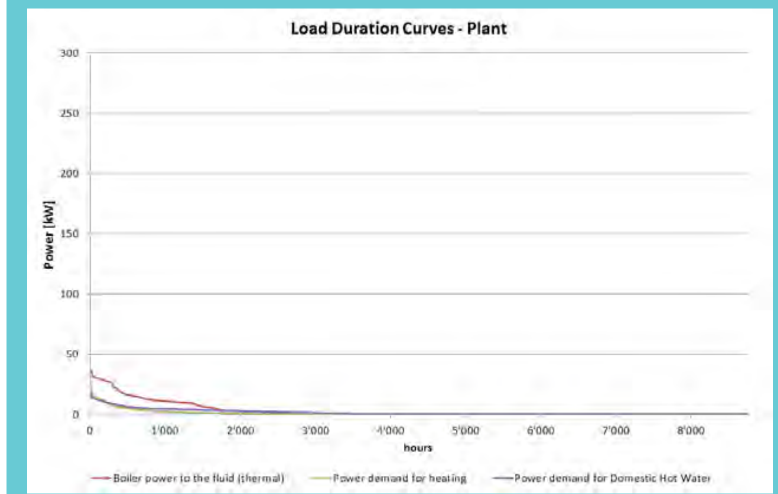


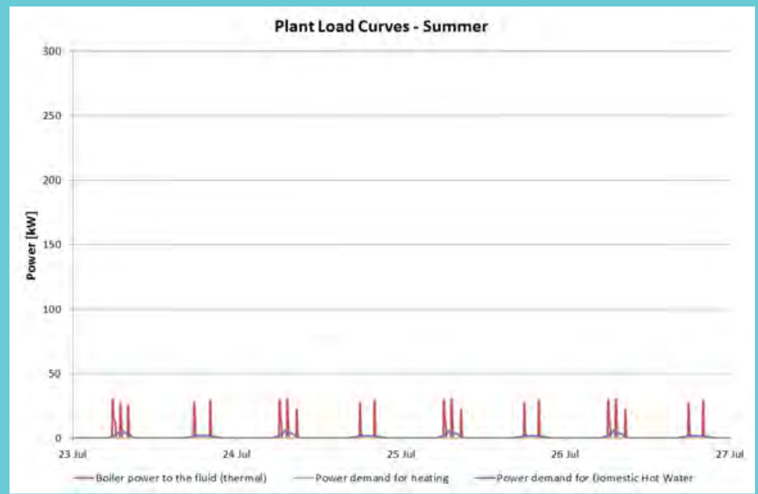


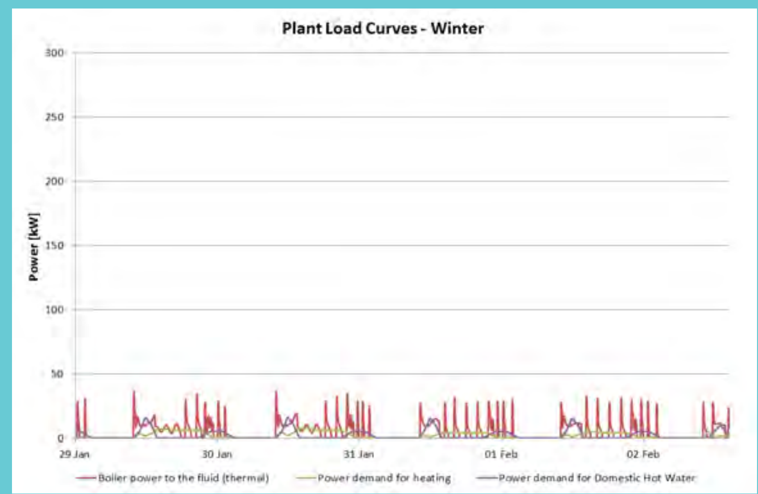




Plant Model - Load Curves







	Unit	Gas	Electricity	Total
Final Energy consumption	kWhFE/m²/y	25.7	39.5	65.2
Primary Energy consumption	kWhPE/m²/y	25.7	101.9	127.6
CO2 Emissions	kgCO2eq/m²/y	6.3	3.2	9.5

4. Annex I: Detailed Results

4.12. Naples - Base Case: Low Envelope, No Control

Control: No Control

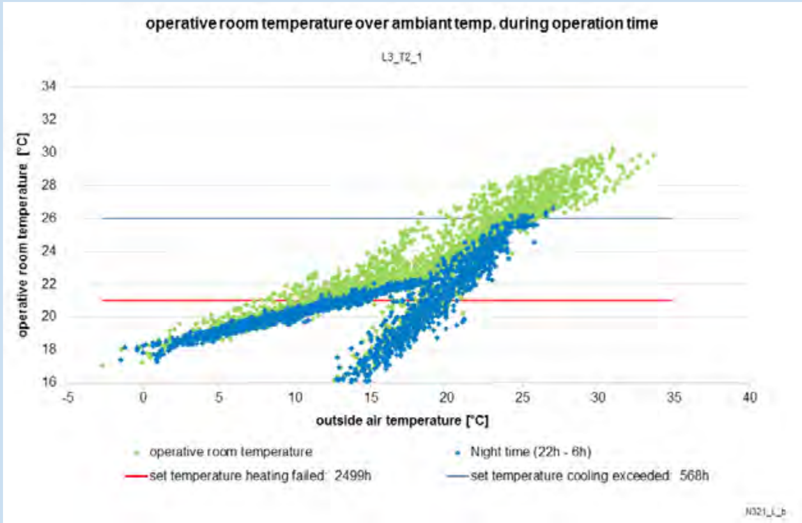
Envelope Perfomance: Low

Heating: Old Boiler - 1 speed burner

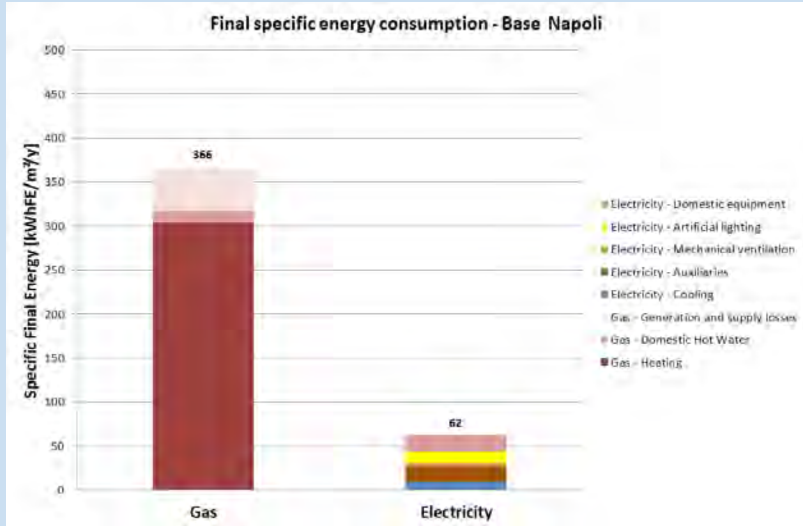
Cooling: Split unit for cooling (low efficiency)

Plant sized following the low envelope demand

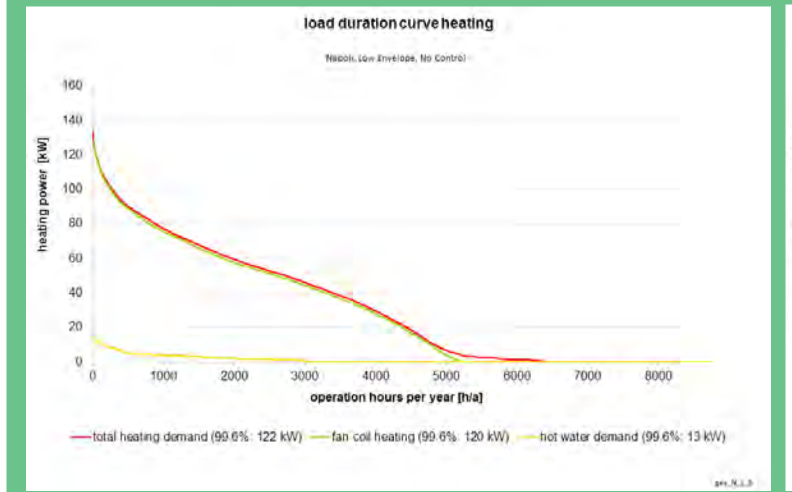
Comfort - Apartment L3_T2 (3rd floor, 2 rooms, SE-SW)

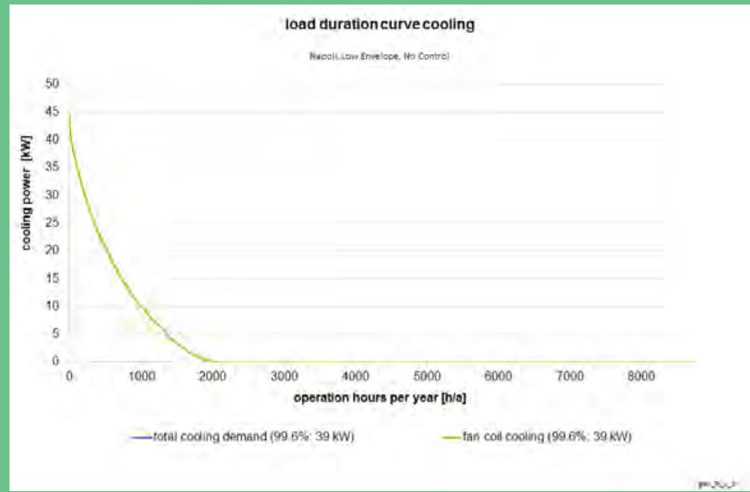


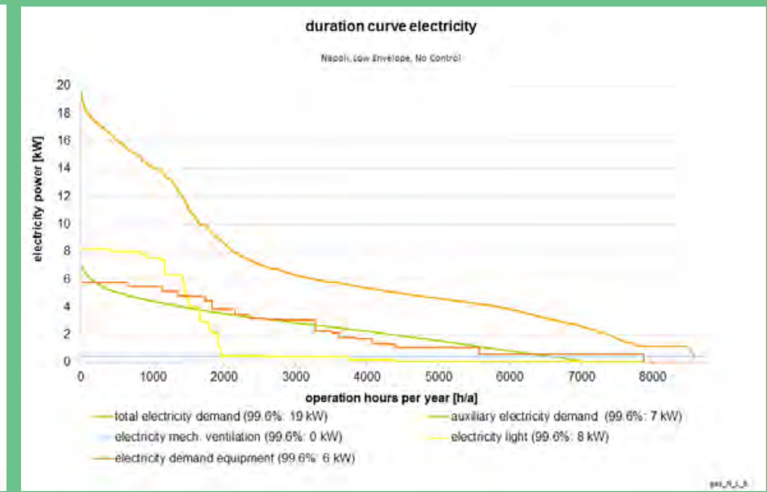
Final Specific Energy Consumption

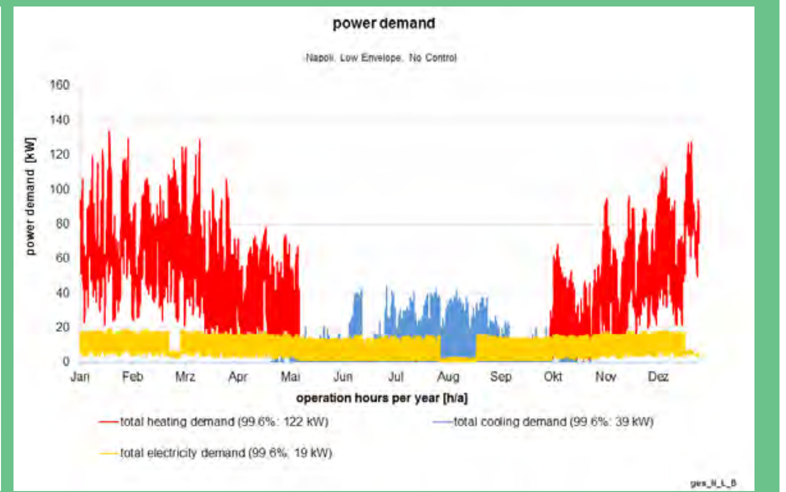


Energy Demand - Load Curves

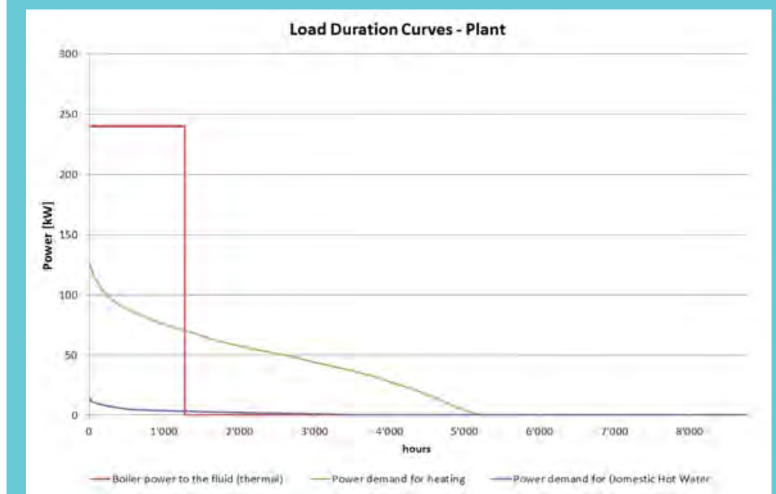


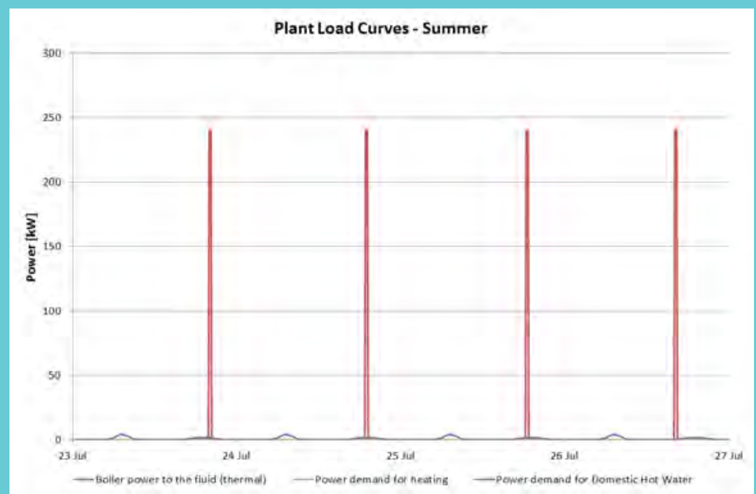


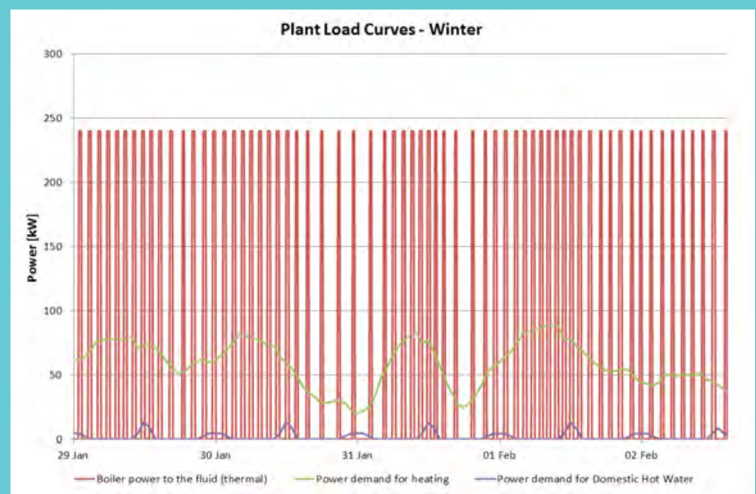




Plant Model - Load Curves







	Unit	Gas	Electricity	Total
Final Energy consumption	kWhFE/m²/y	366.4	61.9	428.3
Primary Energy consumption	kWhPE/m²/y	384.7	149.8	534.5
CO2 Emissions	kgCO2eq/m²/y	73.2	26.8	100.0

4.13. Naples - Case 2: Good Envelope Performance, Night Time Reduction, Thermostat on Radiator

Control: Night Time Reduction, Thermostat on Radiators

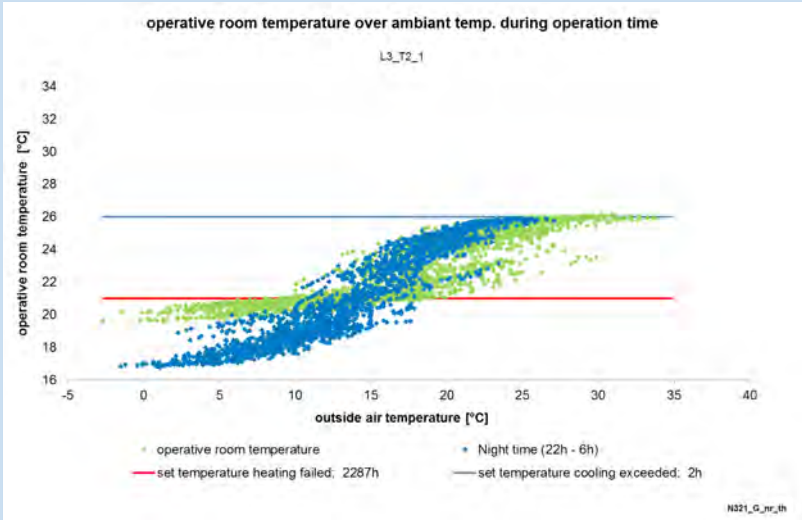
Envelope Perfomance: Good

Heating: New condensing boiler - modulating burner

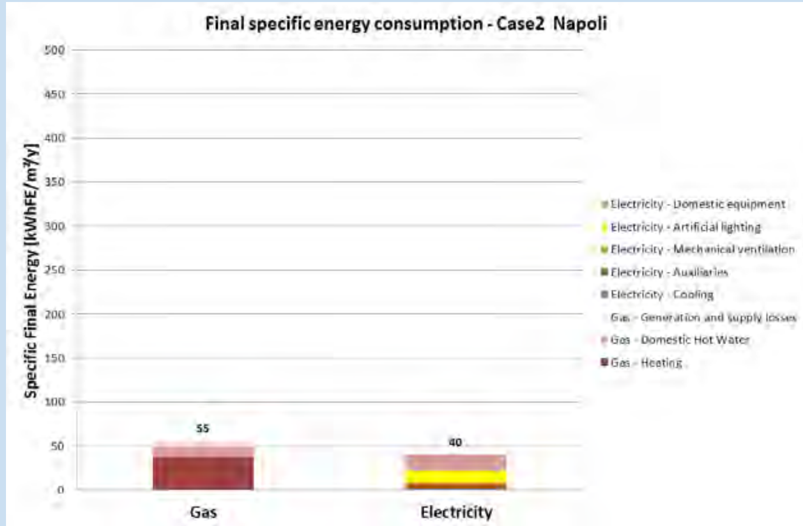
Cooling: Split unit for cooling (high efficiency)

Plant sized following the good envelope demand

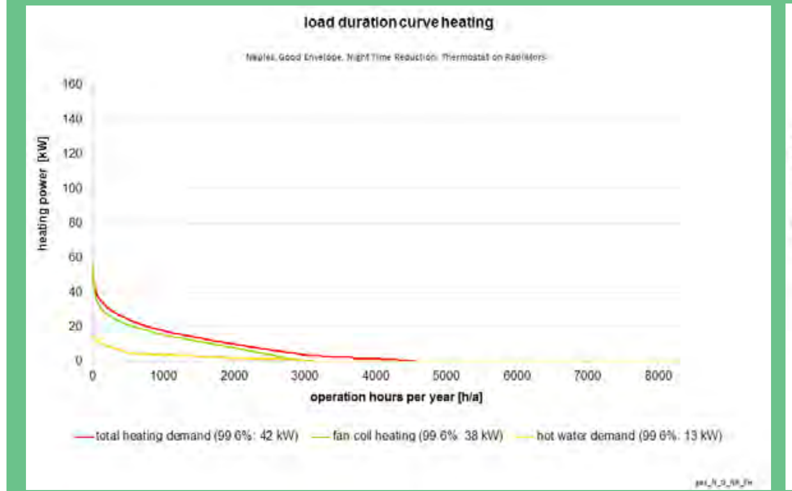
Comfort - Apartment L3_T2 (3rd floor, 2 rooms, SE-SW)

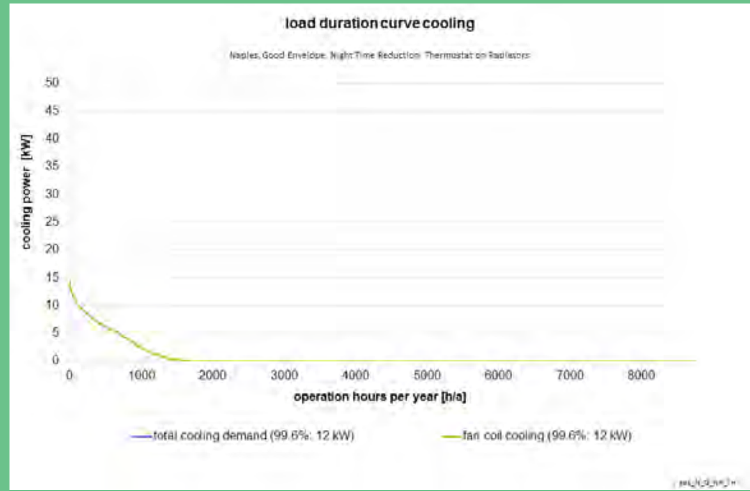


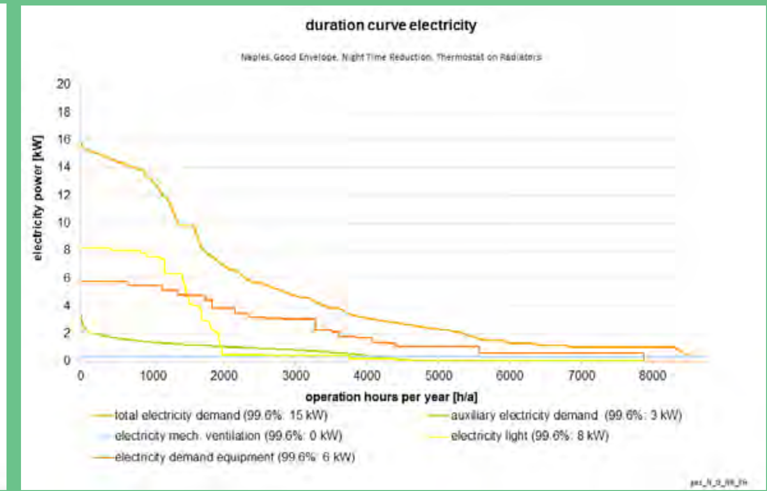
Final Specific Energy Consumption

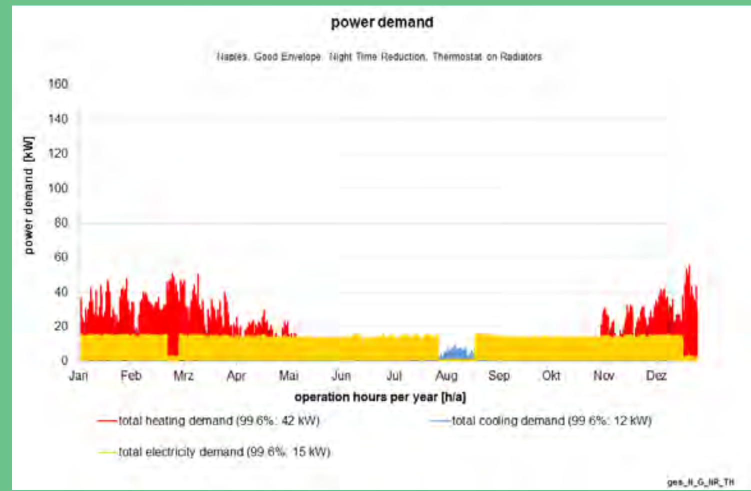


Energy Demand - Load Curves

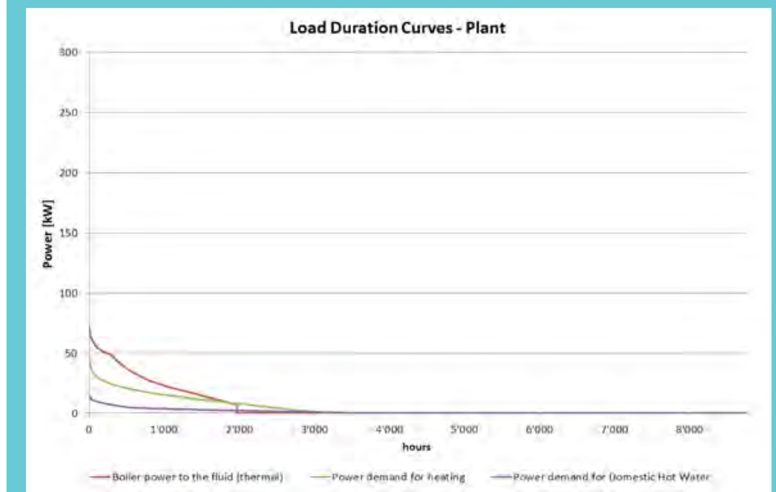


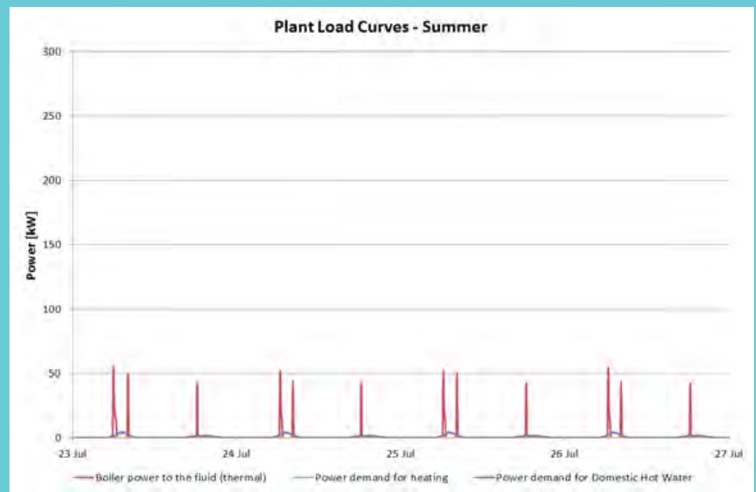


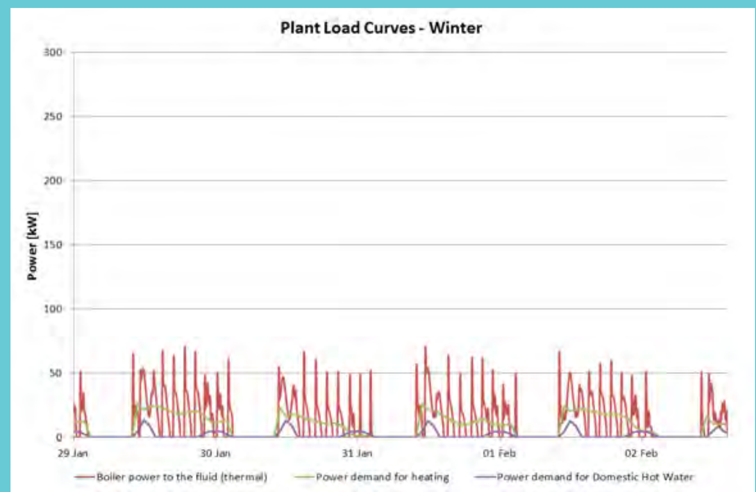




Plant Model - Load Curves







	Unit	Gas	Electricity	Total
Final Energy consumption	kWhFE/m²/y	55.2	40.2	95.4
Primary Energy consumption	kWhPE/m²/y	55.2	103.8	159.0
CO2 Emissions	kgCO2eq/m²/y	13.4	3.3	16.7

4.14. Naples - Case 3: Excellent Envelope Performance, Night Time Reduction, Thermostat on Radiator

Control: Night Time Reduction, Thermostat on Radiators

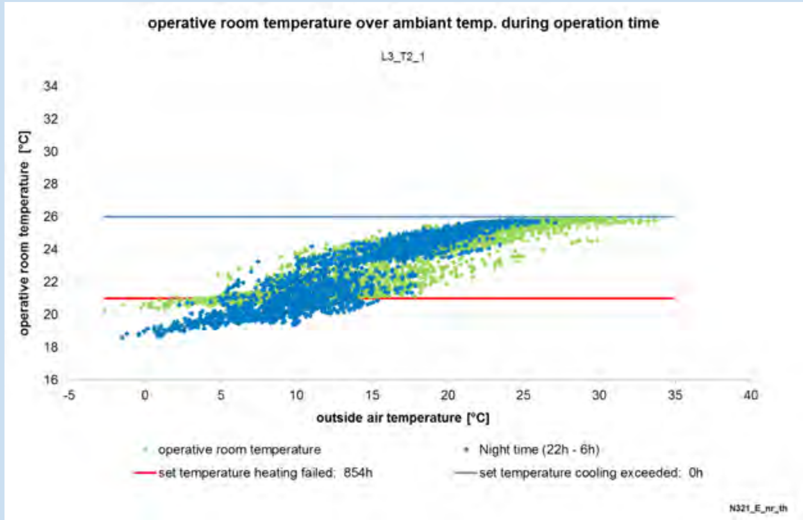
Envelope Perfomance: Excellent

Heating: New condensing boiler - modulating burner

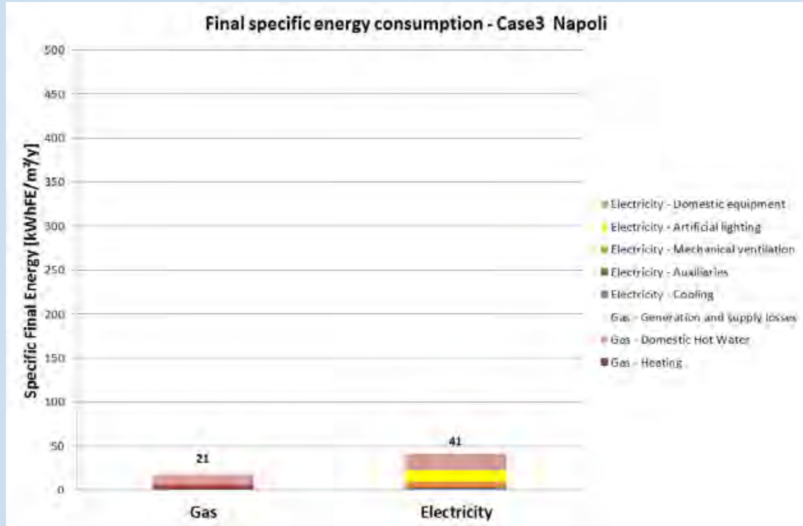
Cooling: Split unit for cooling (high efficiency)

Plant sized following the excellent envelope demand

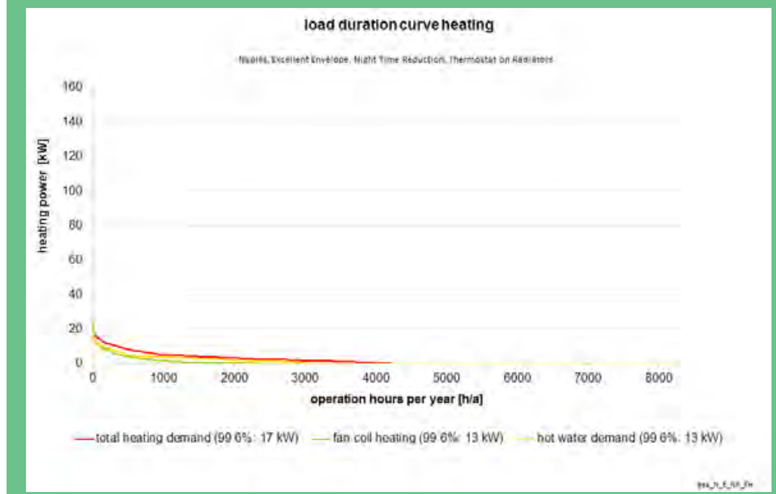
Comfort - Apartment L3_T2 (3rd floor, 2 rooms, SE-SW)

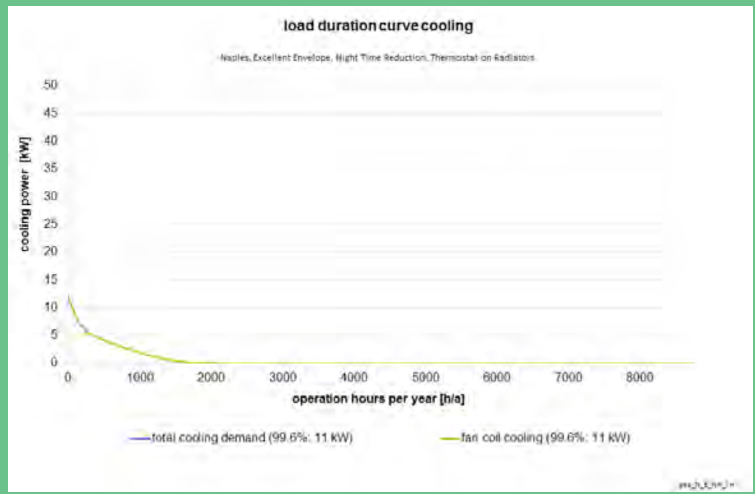


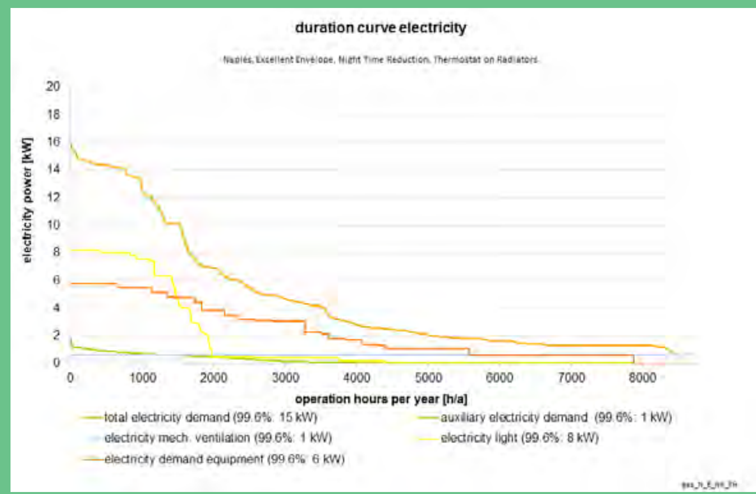
Final Specific Energy Consumption

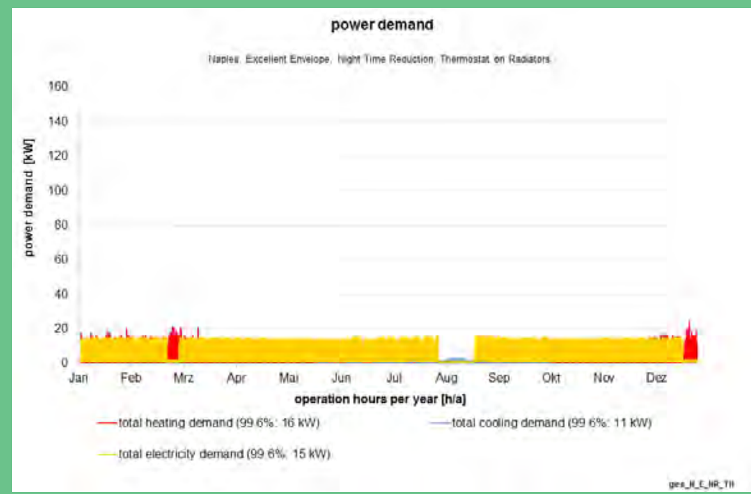


Energy Demand - Load Curves

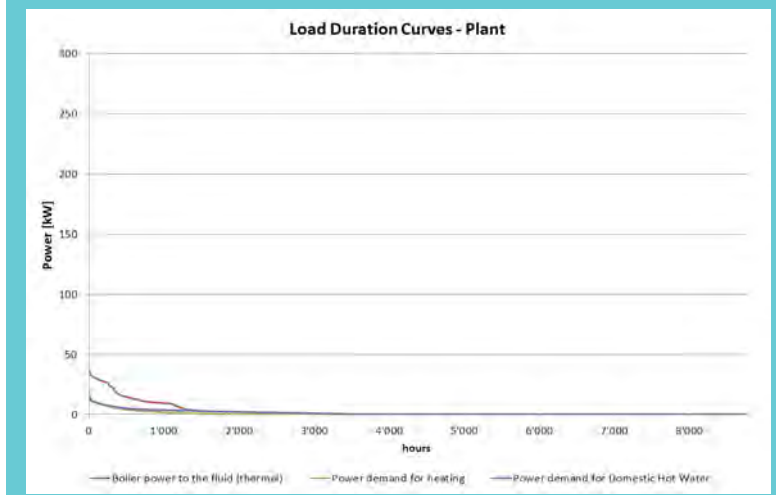


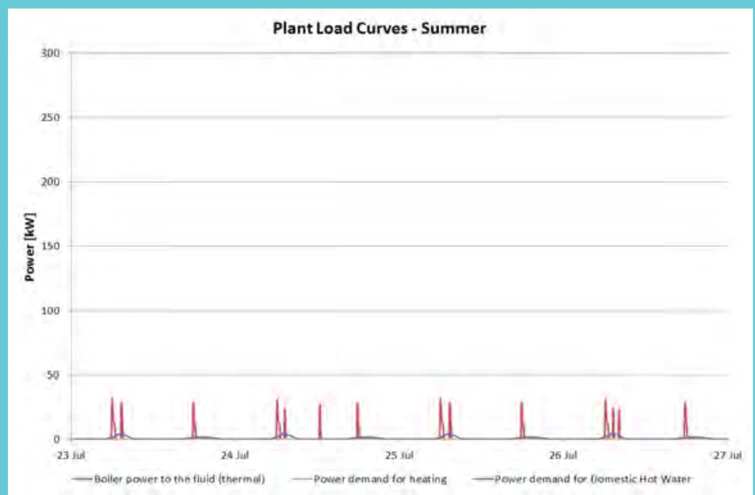


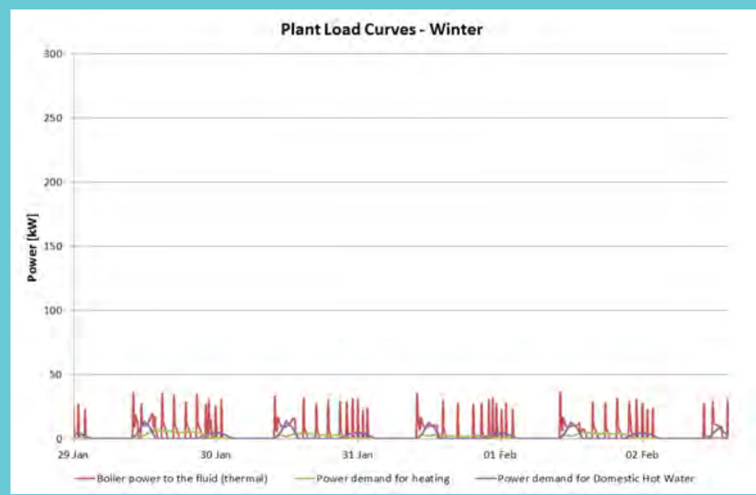




Plant Model - Load Curves







	Unit	Gas	Electricity	Total
Final Energy consumption	kWhFE/m²/y	21.3	40.8	**62.1**
Primary Energy consumption	kWhPE/m²/y	21.3	105.3	**126.6**
CO2 Emissions	kgCO2eq/m²/y	5.2	3.3	**8.5**

4.15. Helsinki - Base Case: Low Envelope, No Control

Control: No Control

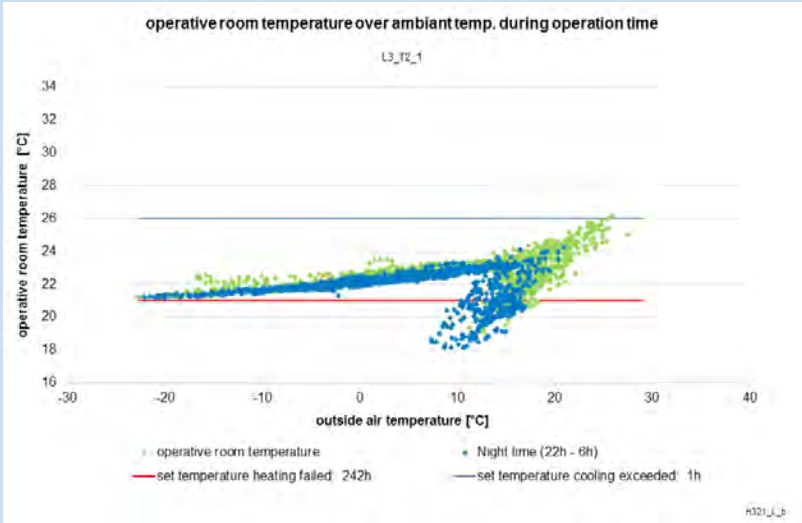
Envelope Perfomance: Low

Heating: Old Boiler - 1 speed burner

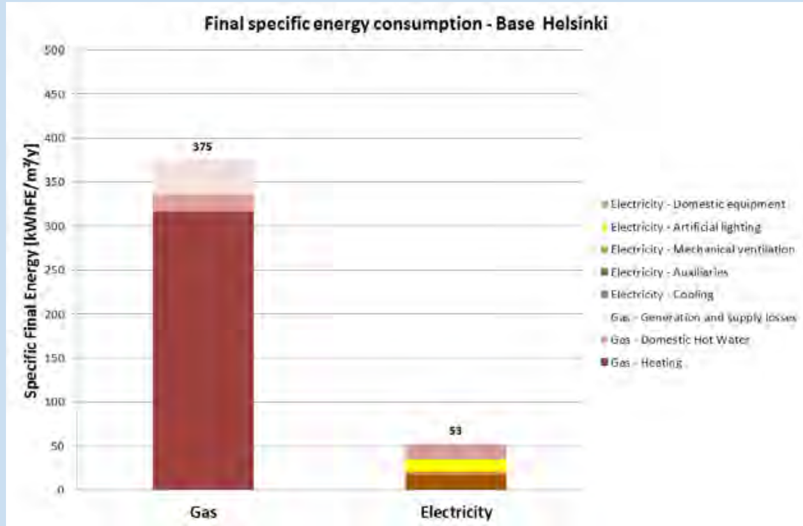
Cooling: Split unit for cooling (low efficiency)

Plant sized following the low envelope demand

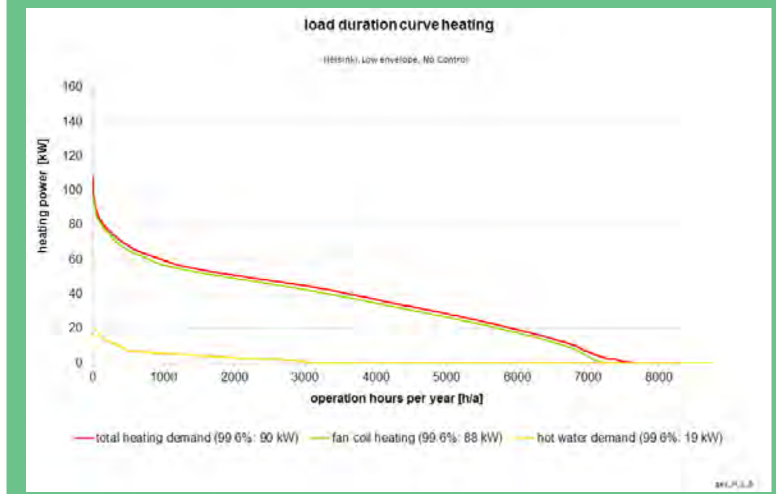
Comfort - Apartment L3_T2 (3rd floor, 2 rooms, SE-SW)

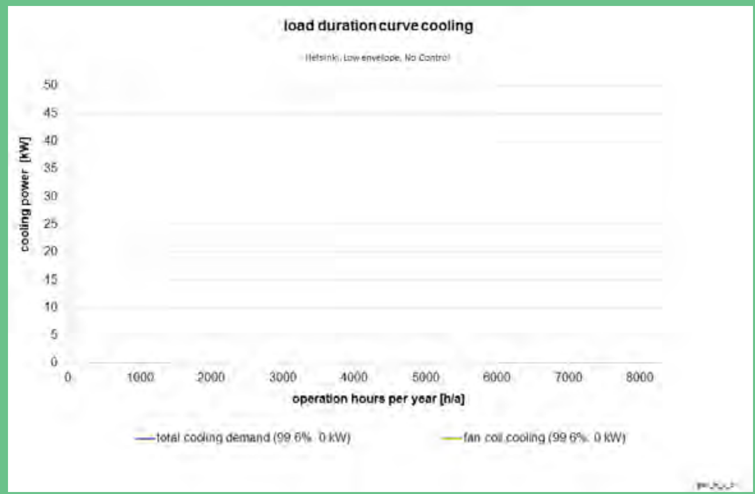


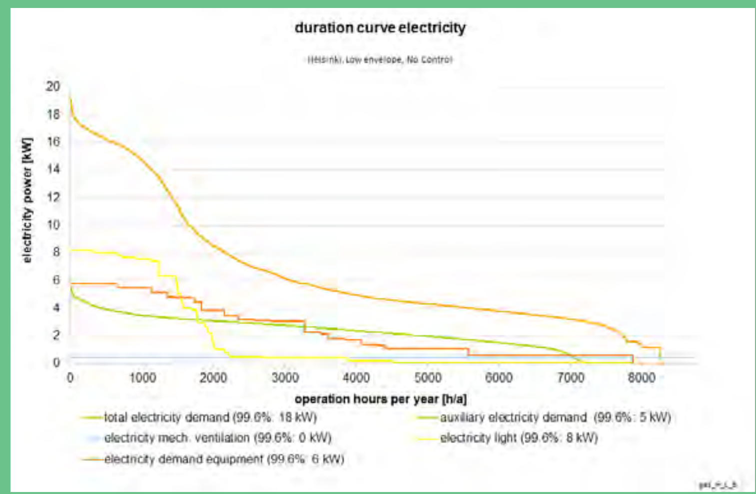
Final Specific Energy Consumption

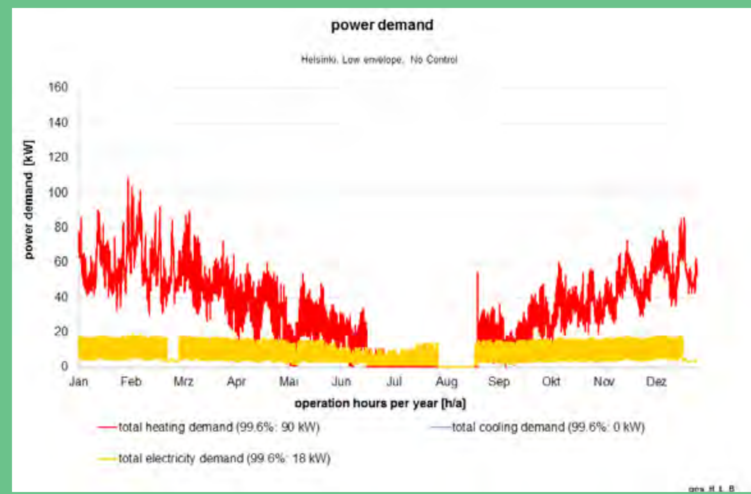


Energy Demand - Load Curves

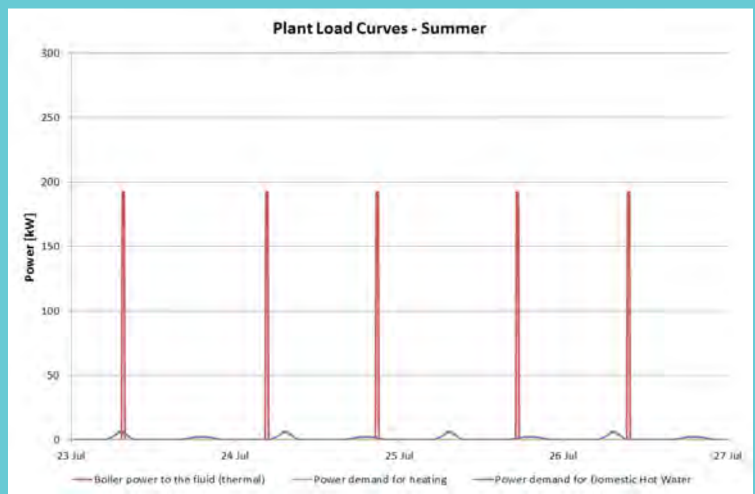


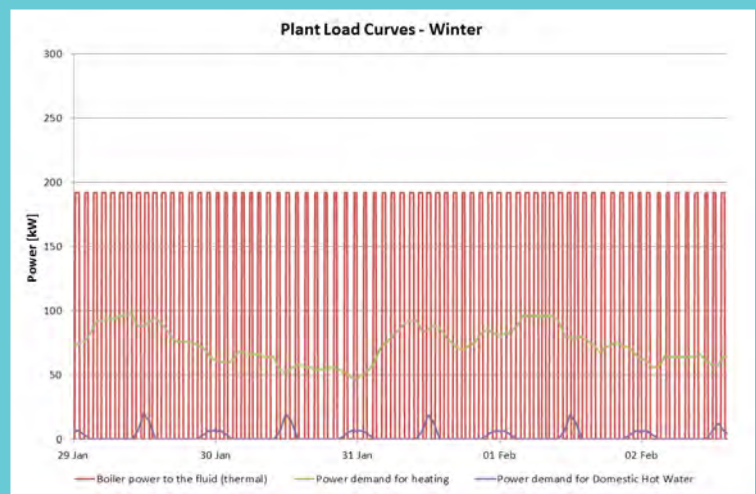






Plant Model - Load Curves





	Unit	Gas	Electricity	Total
Final Energy consumption	kWhFE/m²/y	375.1	52.8	427.9
Primary Energy consumption	kWhPE/m²/y	375.1	89.8	464.9
CO2 Emissions	kgCO2eq/m²/y	118.2	17.5	135.6

4. Annex I: Detailed Results
4.16. Helsinki - Case 2: Good Envelope Performance, Night Time Reduction, Thermostat on Radiators

Control: Night Time Reduction, Thermostat on Radiators

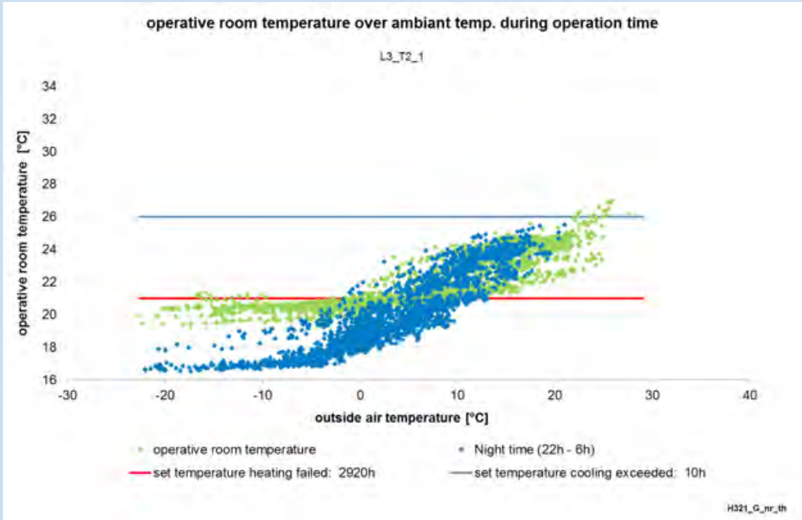
Envelope Perfomance: Good

Heating: New condensing boiler - modulating burner

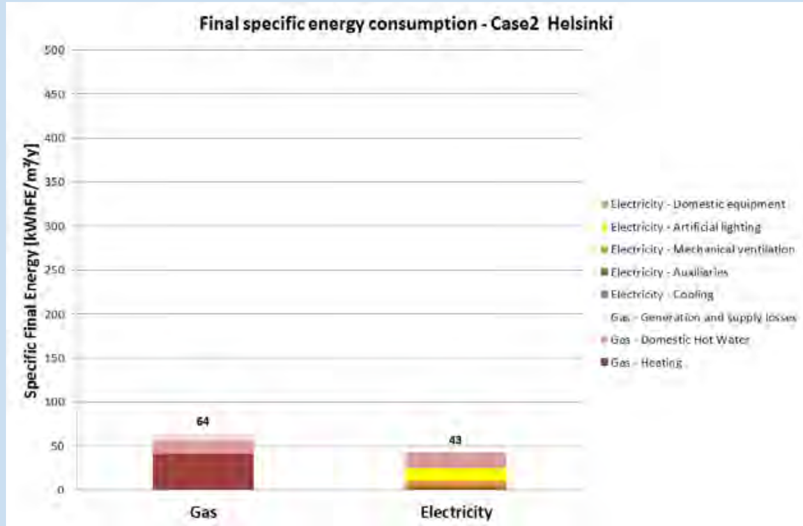
Cooling: Split unit for cooling (high efficiency)

Plant sized following the good envelope demand

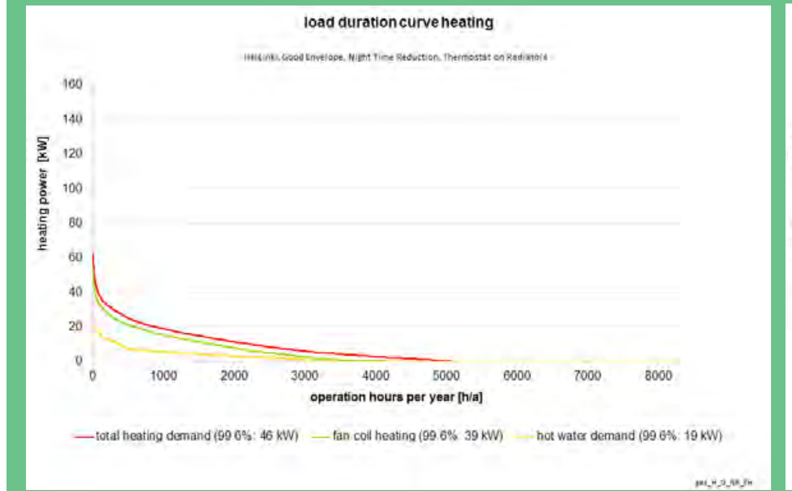
Comfort - Apartment L3_T2 (3rd floor, 2 rooms, SE-SW)

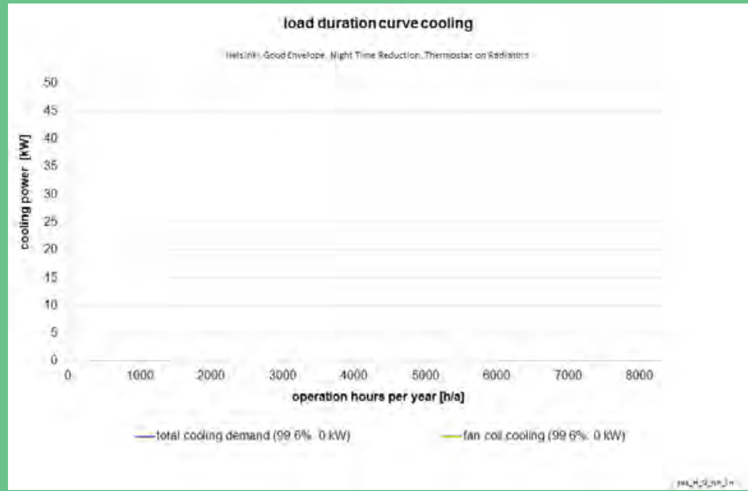


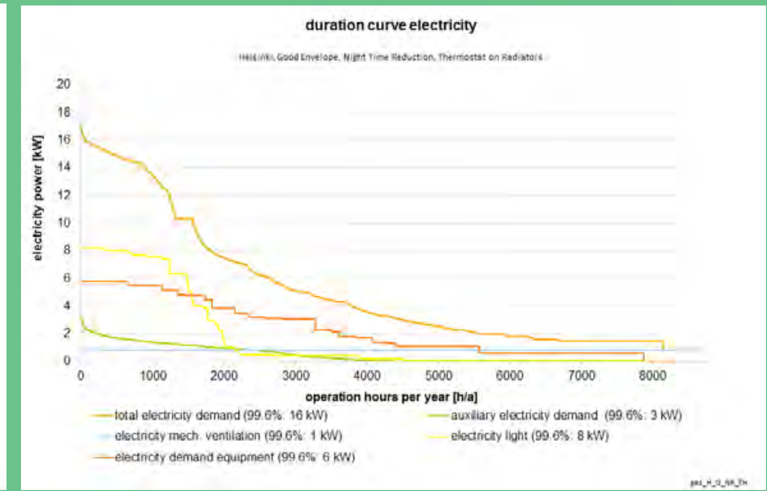
Final Specific Energy Consumption

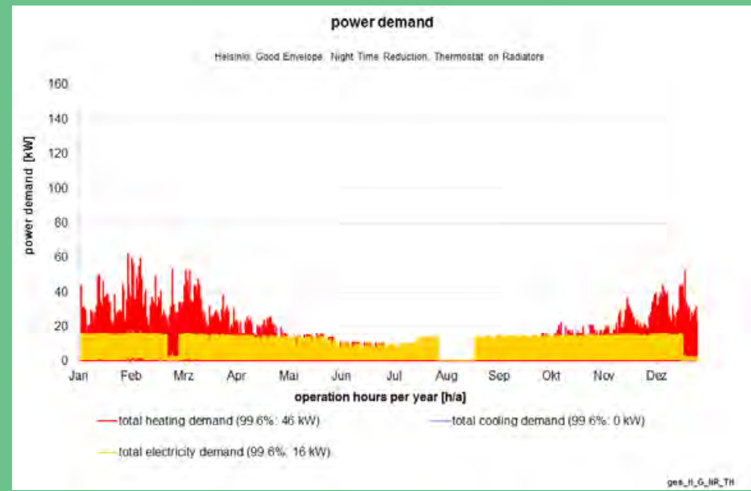


Energy Demand - Load Curves

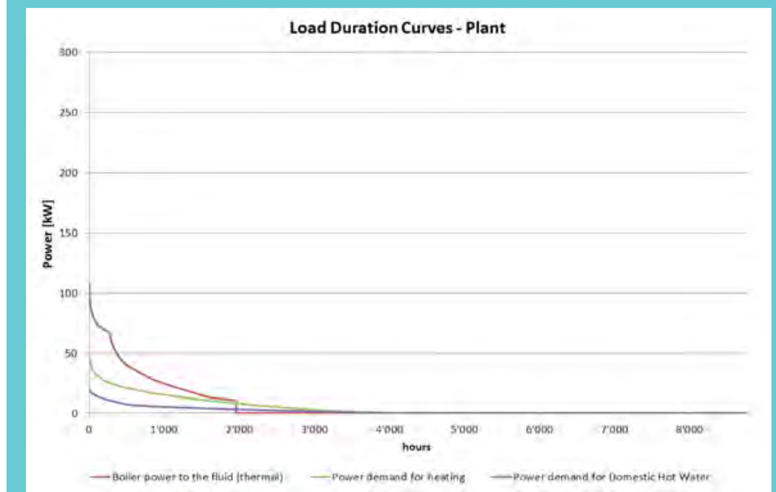


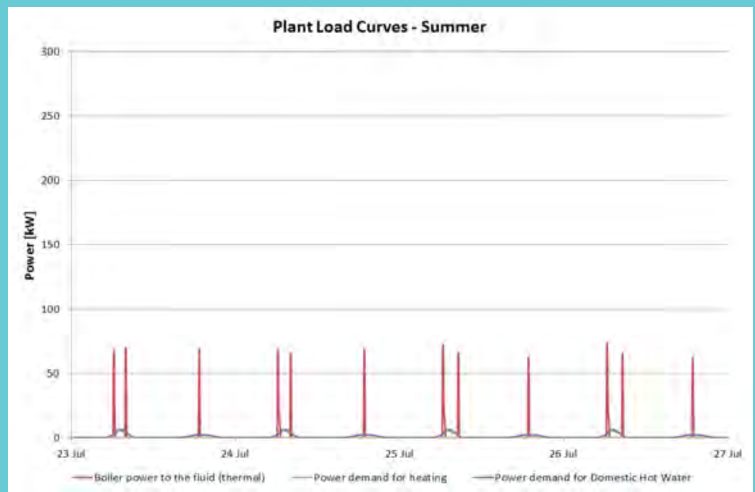


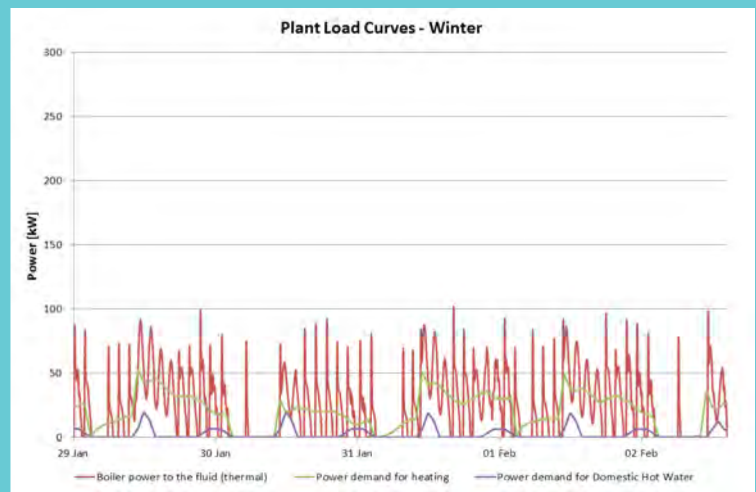




Plant Model - Load Curves







	Unit	Gas	Electricity	Total
Final Energy consumption	kWhFE/m²/y	64.0	42.8	106.8
Primary Energy consumption	kWhPE/m²/y	64.0	110.4	174.5
CO2 Emissions	kgCO2eq/m²/y	15.6	3.5	19.1

4.17. Helsinki - Case 3: Excellent Envelope Performance, Night Time Reduction, Thermostat on Radiators

Control: Night Time Reduction, Thermostat on Radiators

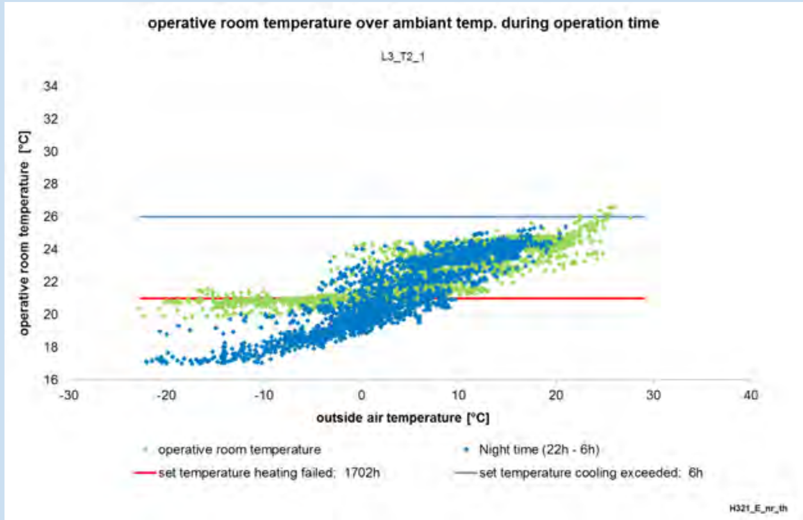
Envelope Perfomance: Excellent

Heating: New condensing boiler - modulating burner

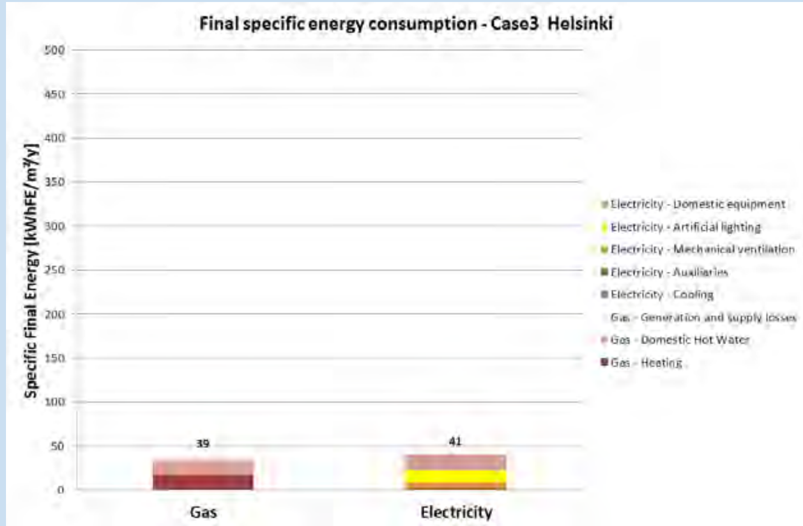
Cooling: Split unit for cooling (high efficiency)

Plant sized following the excellent envelope demand

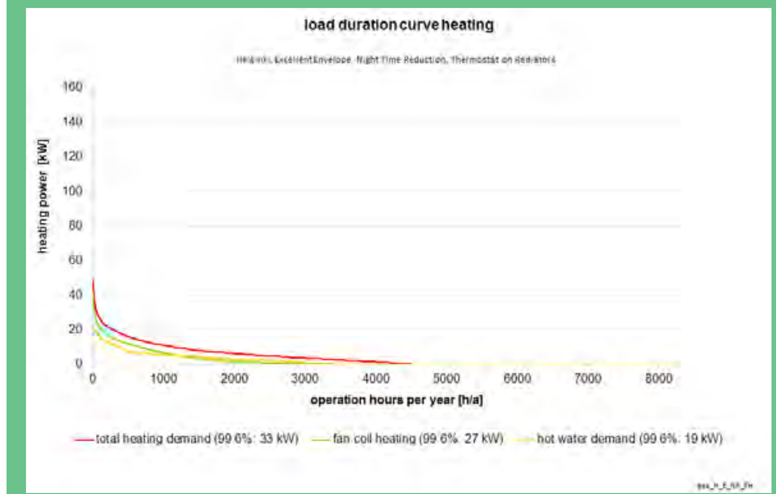
Comfort - Apartment L3_T2 (3rd floor, 2 rooms, SE-SW)

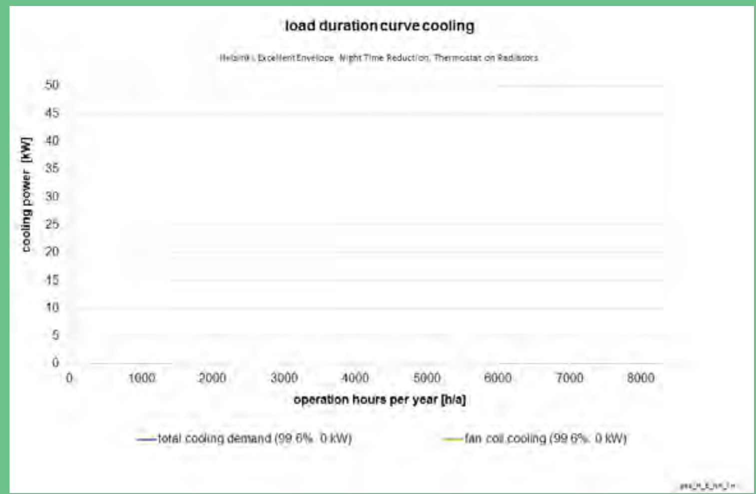


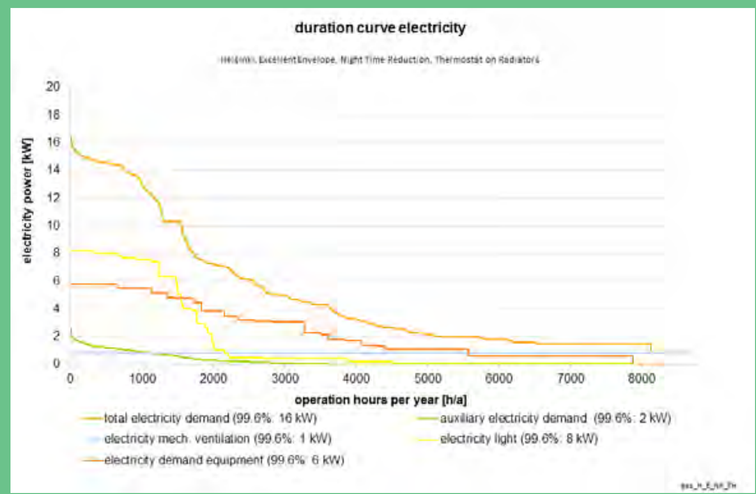
Final Specific Energy Consumption

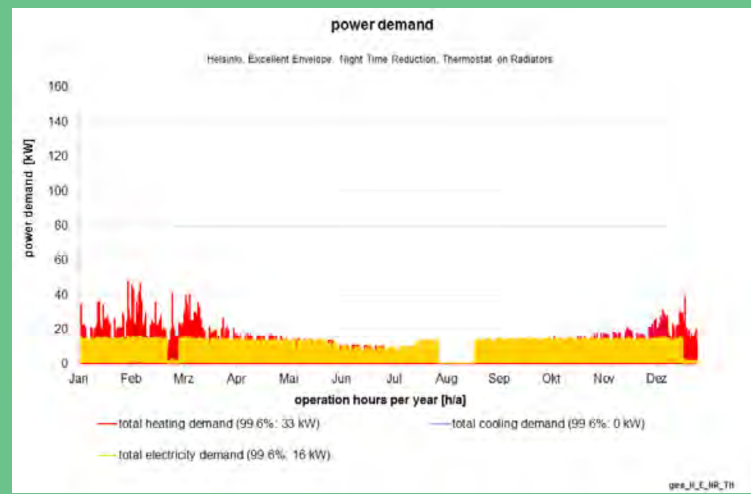


Energy Demand - Load Curves

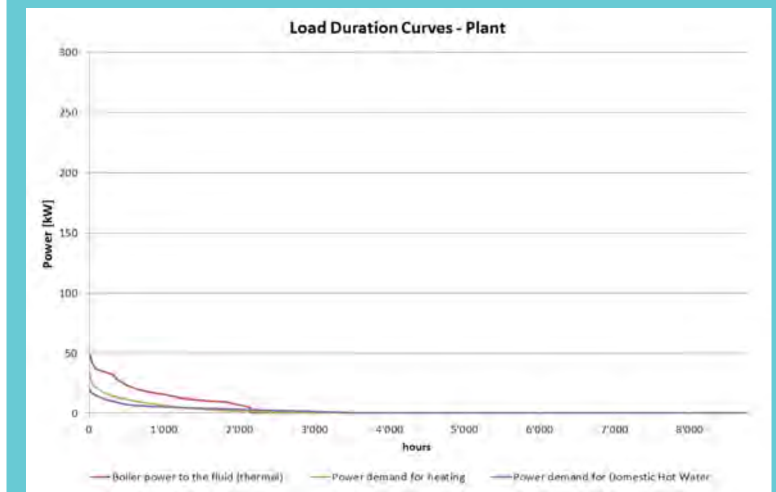


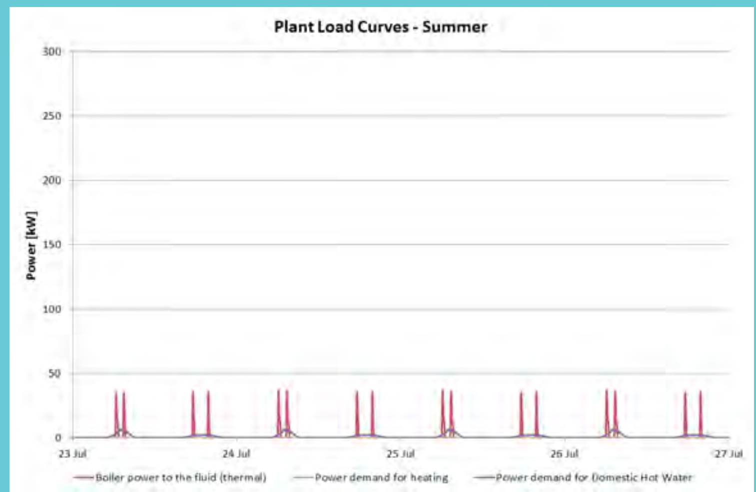


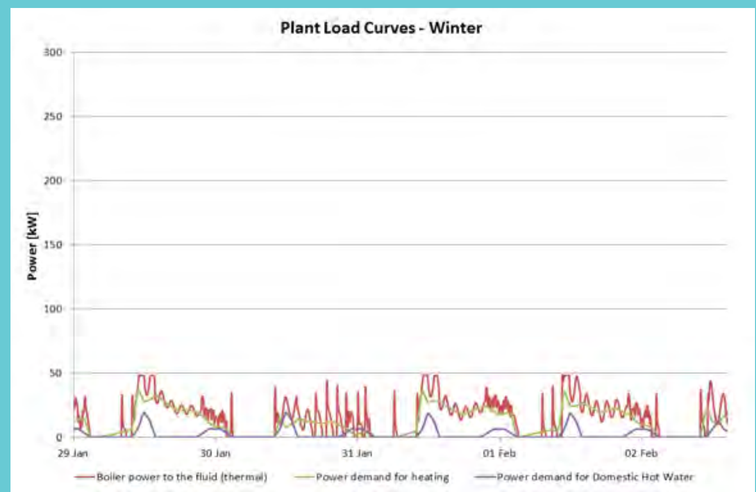




Plant Model - Load Curves







	Unit	Gas	Electricity	Total
Final Energy consumption	kWhFE/m²/y	21.3	40.8	62.1
Primary Energy consumption	kWhPE/m²/y	21.3	105.3	126.6
CO2 Emissions	kgCO2eq/m²/y	5.2	3.3	8.5

5. ANNEX II: Boundary Conditions

5. ANNEX II - Boundary Conditions
5.1. Modeling

This document summarizes the boundary conditions for the thermal modeling to be done with Trnsys during Phase 2 and 3.
The building to be modeled is a 3-story residential building
The boundary conditions for the building geometry, building operation and domestic hot water demand are the same for all variants.

Weather Data
4 different climate have been selected for this study

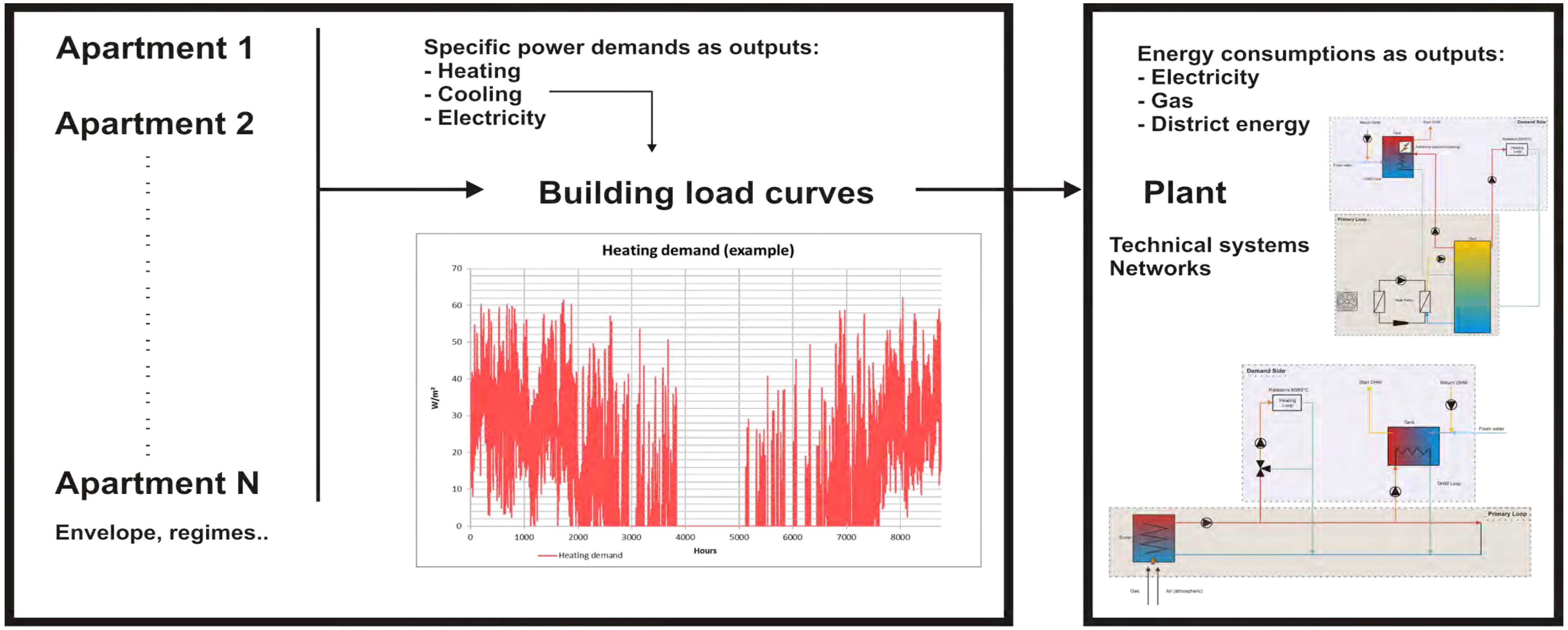
Climate	Weather data
Mediterranean	IWEC Naples
Oceanic	IWEC Paris Orly
Oceanic - Heat Wave	Predicted weather data for Paris, using the Meteonorm v7 software for Paris Montsouris, and taking into account the A2 IPCC scenario for 2020 This weather data is only used to study summer comfort during a typical Parisian Heat wave for different envelope typologies.
Continental	IWEC Helsinki

Modeling
TRNSYS uses legal winter time all year long. As an example, simulations in Paris are all based on GMT+1.

A 2 steps approach is followed to model the building.

Step 1 : A dynamic thermal simulation using TRNSYS is modeling the building as it is defined independently from the plant settings, with ideal heating and cooling demands.
Ideal space heating and space cooling demands represent the exact amount of energy needed to reach setpoint temperature in winter and summer in the room.
It doesn't take into account any efficiency of the heating and cooling production systems.
Heating and cooling demands are processed to get annual heating and cooling load curves over the whole building.

Step 2 : The load curves are used as inputs for a second dynamic simulation which is modeling the plant (energy production, regulation, efficiencies).
This second calculation gives as results the final energy consumption, primary energy consumption, and the carbon emissions.

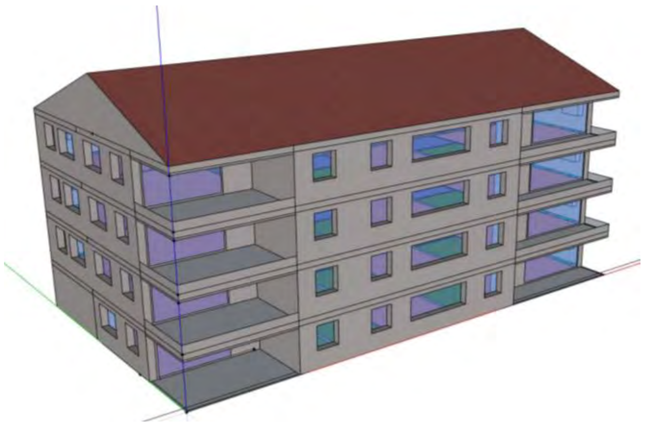


STEP 1 - TRNsys

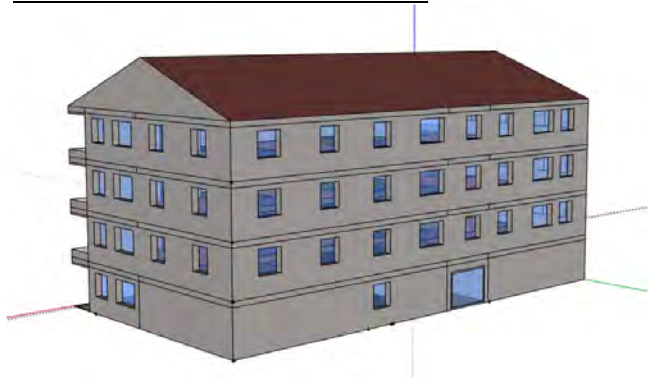
STEP 2 - TRNsys

GEOMETRY

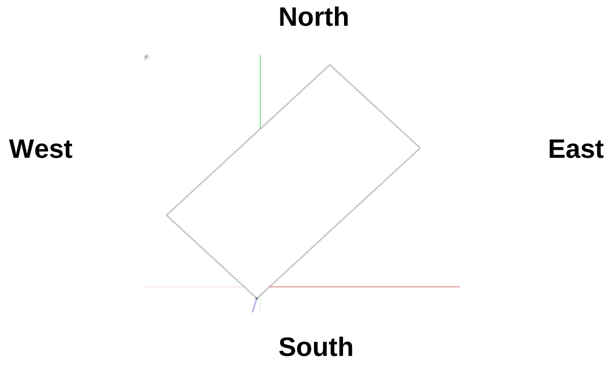
South East and South West Façade



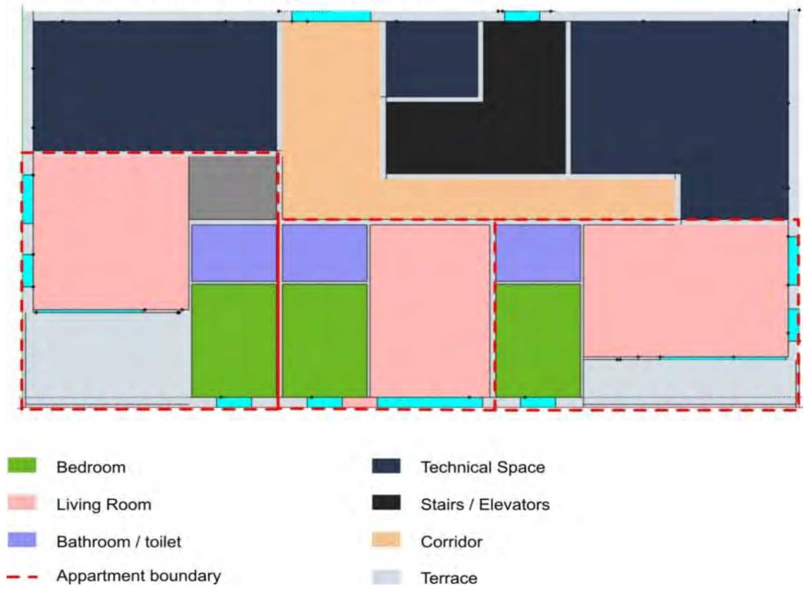
North West and North East Facade



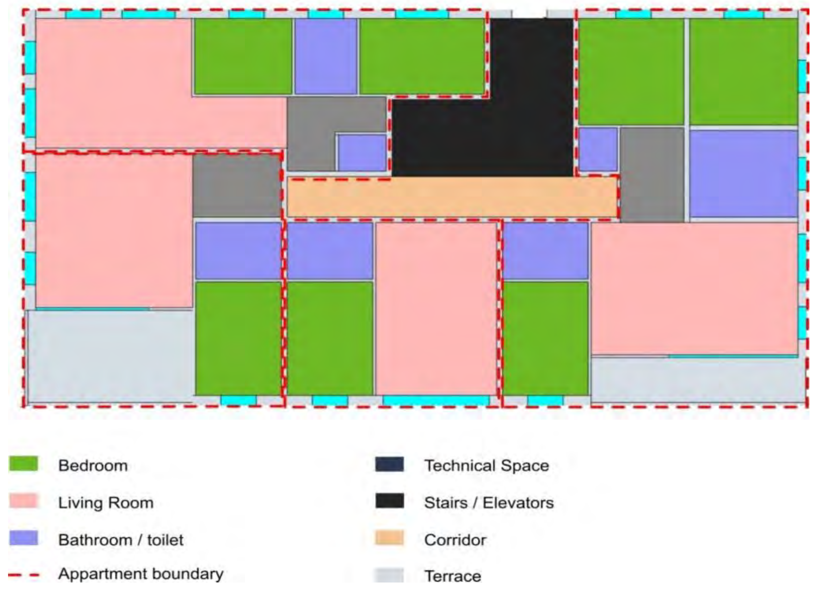
Top View



Residential Building - Groundfloor



Residential Building - Level 1 to 3



Façade	NW	NE	SE	SW	Total
Façade area [m²]	308.4	170.5	308.4	170.5	957.9
Window area [m²]	51.1	25.9	115.0	28.4	220.3
Ratio	17%	15%	37%	17%	23%

Netto Area [m²]	T2_1	T2_2	T2_3	T3_1	T4_1	Corr	Stairs	Unheated
L0	55.67	44.96	52.63	-	-	39.78	24.65	96.93
L1	55.67	44.51	-	67.37	102.55	16.78	25.87	-
L2	55.67	44.51	-	67.37	102.55	16.78	25.87	-
L3	55.67	44.51	-	67.37	102.55	16.78	25.87	-
Total	**222.68**	**178.49**	**52.63**	**202.10**	**307.65**	**90.11**	**102.26**	**96.93**

Total appartments [m²]	963.55
Total corridor [m²]	90.11
Total unconditionned space [m²]	96.93

5. ANNEX II - Boundary Conditions
5.3. Operation

OPERATION

	Occupation			Domestic Equipments		Artificial Lighting				Ventilation		Comfort		Domestic Hot Water	
	Daily schedule	Holiday Schedule	Number of people	Power density	Daily Schedule	Power density	Illuminance Setpoint	Control	Daily Schedule	Mechanical Ventilation Airchange	Natural Ventilation through Window openning (summer comfort)	Temperature Setpoint - Winter	Temperature Setpoint - Summer	DHW Outlet Temperature	Daily DHW volume per person
	[-]	[-]	[pers]	[W/m²]	[-]	[W/m²]	lux	[-]	[-]	[ACH]	[-]	[°C]	[°C]	[°C]	[L/p/day]
Programs															
two-rooms appartment	occ_2r_apartment	holiday_year	1	5.7	equip_2r_apartment	7.1	300	DLF	light_2r_apartment	0.60	yes	21°C	26°C	40	50
three-rooms appartment	occ_3r_apartment	holiday_year	3	5.7	equip_3r_apartment	6.9	300	DLF	light_3r_apartment	0.60	yes	21°C	26°C	40	50
four-rooms appartment	occ_4r_apartment	holiday_year	4	5.7	equip_4r_apartment	7.2	300	DLF	light_4r_apartment	0.60	yes	21°C	26°C	40	50
corridor	-	-	-	0.0	-	5.0	100	SCHED	light_corridor	-	no	19°C	-	-	-
stairs & elevators	-	-	-	0.0	-	5.0	150	SCHED	light_corridor	-	no	19°C	-	-	-
entrance hall	-	-	-	0.0	-	5.0	100	SCHED	light_corridor	-	no	19°C	-	-	-
														-	-

<u>Vacations</u>

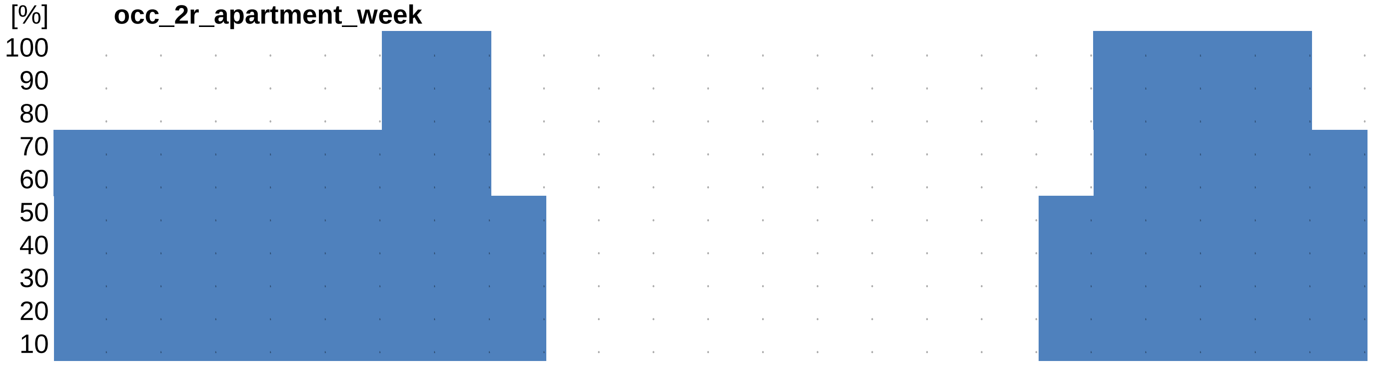
Winter vacations:	Last week of February
Summer vacations:	3 first weeks of August
Christmas vacations:	Last week of December

SCENARII - OCCUPATION & DOMESTIC EQUIPMENTS & ARTIFICIAL LIGHTING

All the following schedules are given without Daylight saving time (GMT +1h)

2-rooms appartment
Young working person
Scenario inspired from the French RT 2012 and the Swiss SIA2024. Adapted according to our experience

occ_2r_apartment_week

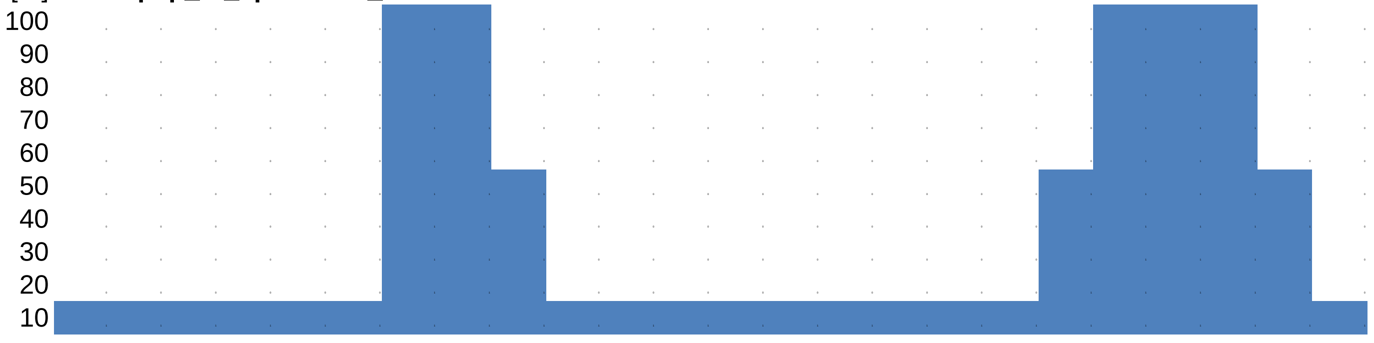


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	70	70	70	70	70	70	100	100	50	0	0	0	0	0	0	0	0	0	50	100	100	100	100	70

occ_2r_apartment_weekend

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	70	70	70	70	70	70	100	100	100	100	50	50	100	100	100	50	50	100	100	100	100	100	70	70

equip_2r_apartment_week

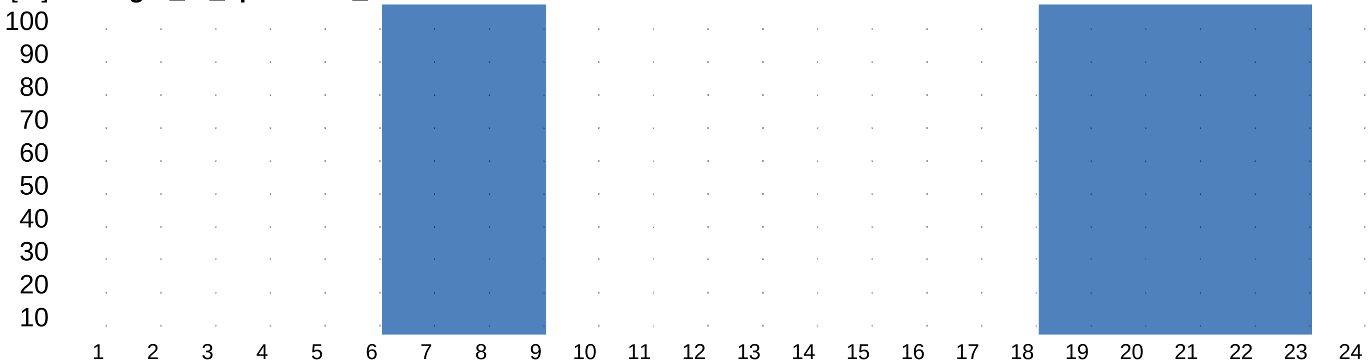


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	10	10	10	10	10	10	100	100	50	10	10	10	10	10	10	10	10	10	50	100	100	100	50	10

equip_2r_apartment_weekend

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	10	10	10	10	10	10	50	100	75	50	50	50	50	100	75	50	50	50	50	100	75	75	10	10

light_2r_apartment_week



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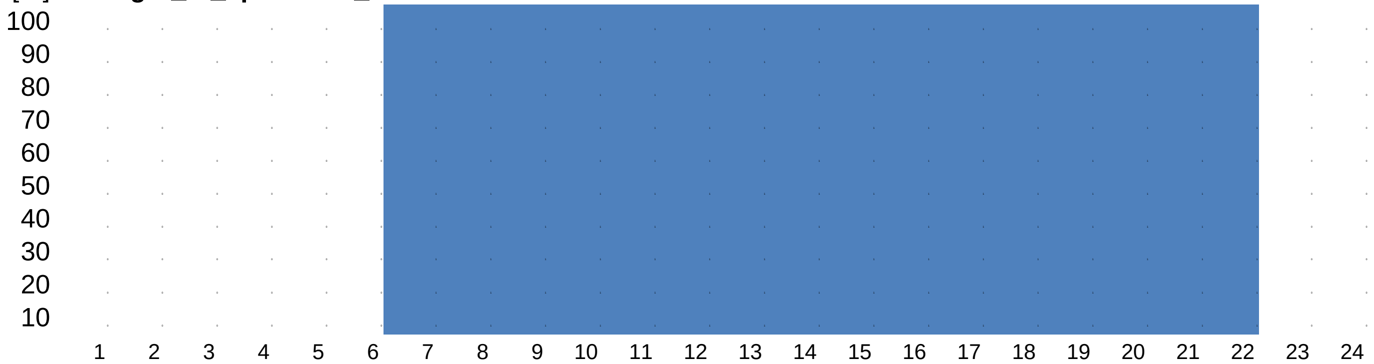
[%]	0	0	0	0	0	0	100	100	100	0	0	0	0	0	0	0	0	0	100	100	100	100	100	0

light_2r_apartment_weekend



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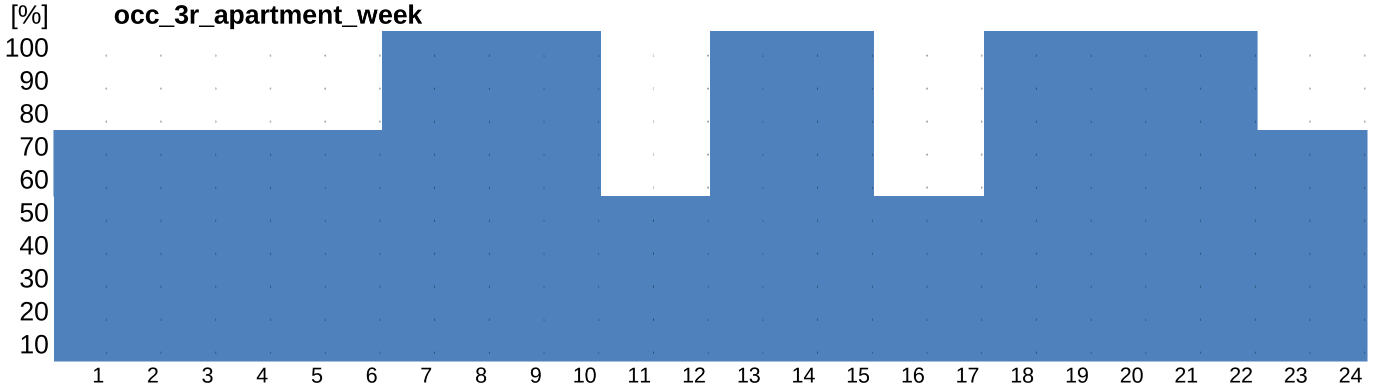
[%]	0	0	0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0	0

SCENARII - OCCUPATION & DOMESTIC EQUIPMENTS & ARTIFICIAL LIGHTING

All the following schedules are given without Daylight saving time (GMT +1h)

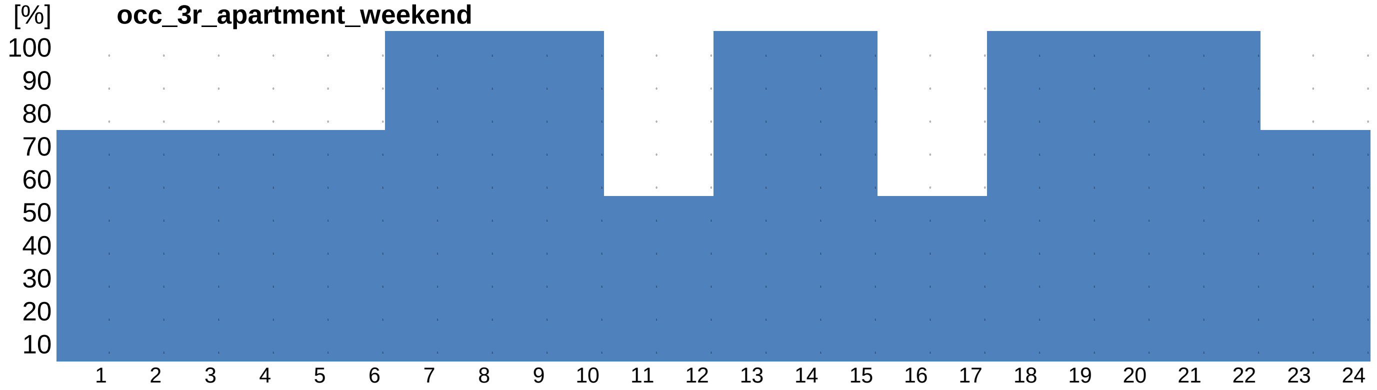
3-rooms appartment
Retired couple
Scenario inspired from the French RT 2012 and the Swiss SIA2024. Adapted according to our experience

occ_3r_apartment_week



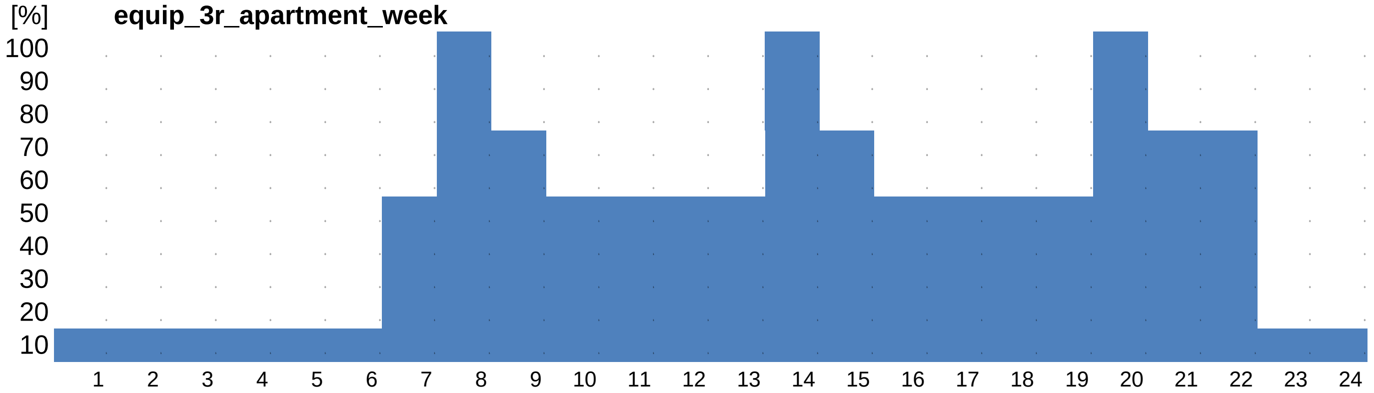
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	70	70	70	70	70	70	100	100	100	100	50	50	100	100	100	50	50	100	100	100	100	100	70	70

occ_3r_apartment_weekend



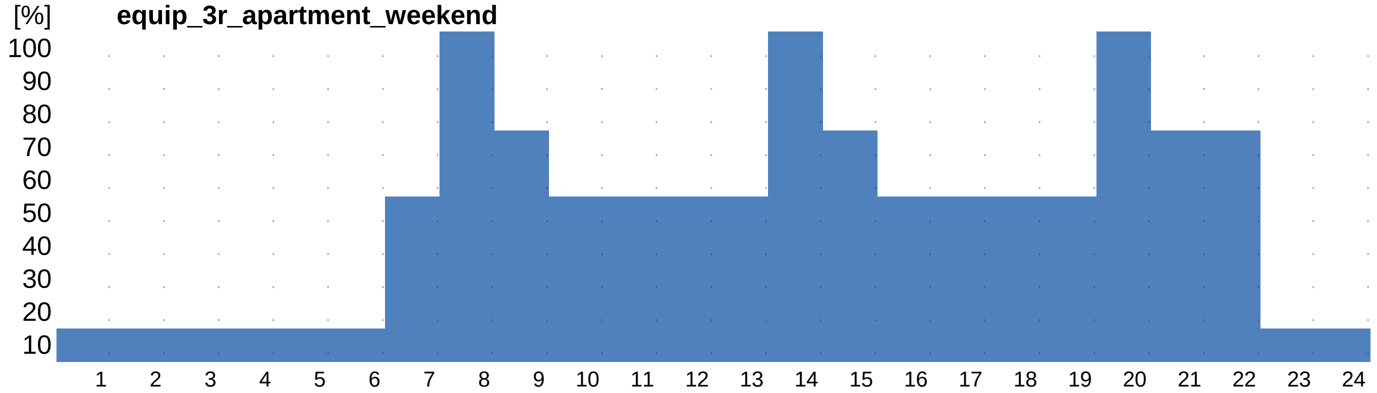
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	70	70	70	70	70	70	100	100	100	100	50	50	100	100	100	50	50	100	100	100	100	100	70	70

equip_3r_apartment_week



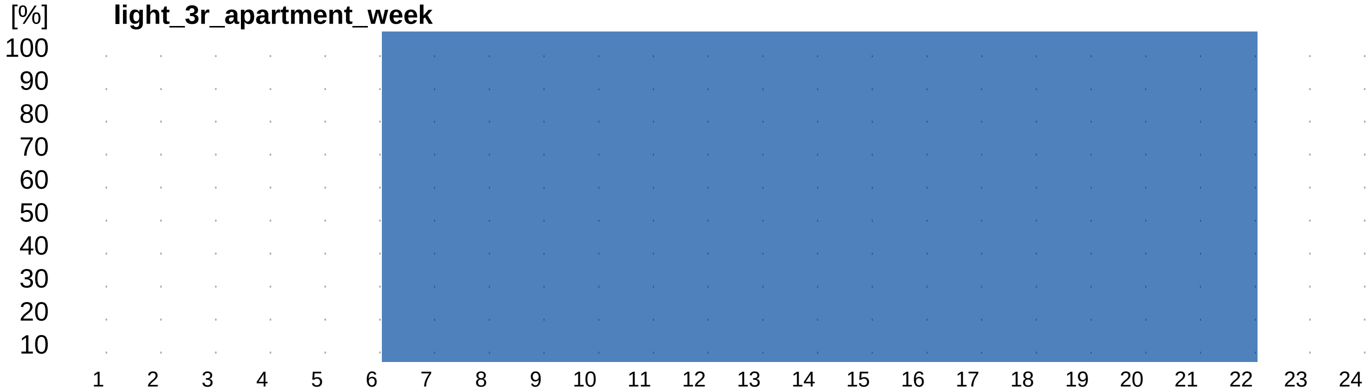
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	10	10	10	10	10	10	50	100	75	50	50	50	50	100	75	50	50	50	50	100	75	75	10	10

equip_3r_apartment_weekend



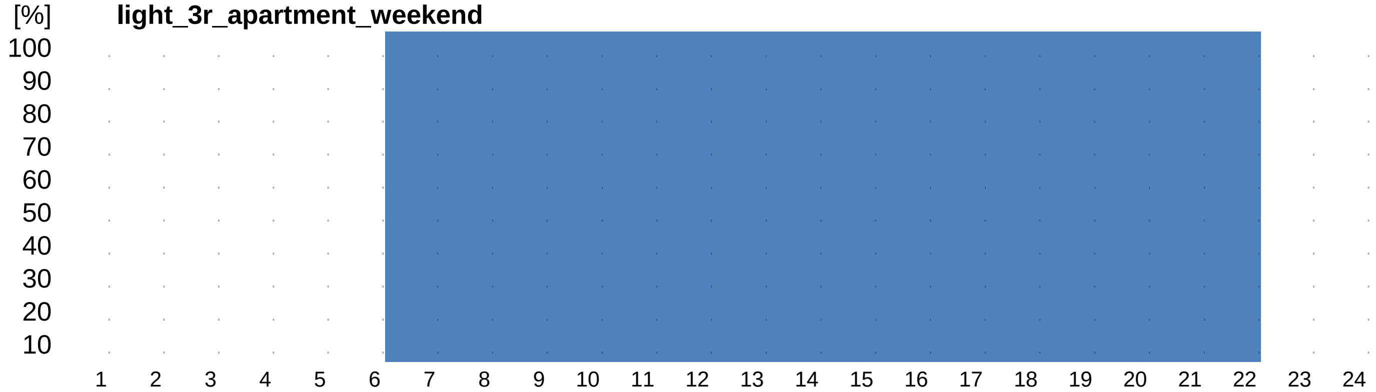
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	10	10	10	10	10	10	50	100	75	50	50	50	50	100	75	50	50	50	50	100	75	75	10	10

light_3r_apartment_week



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	0	0	0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0	0

light_3r_apartment_weekend



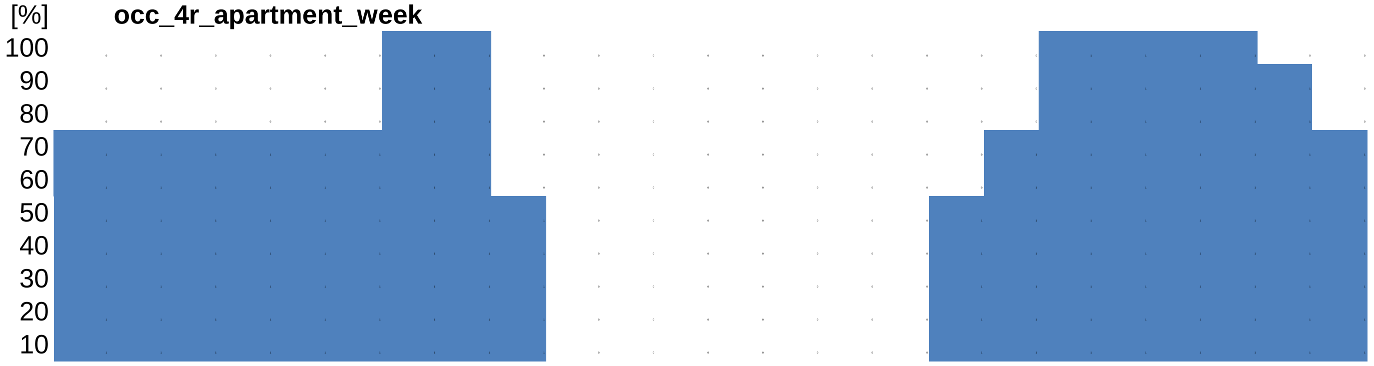
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	0	0	0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0	0

SCENARII - OCCUPATION & DOMESTIC EQUIPMENTS & ARTIFICIAL LIGHTING

All the following schedules are given without Daylight saving time (GMT +1h)

4-rooms appartment
Family apartment
2 parents, 2 teenagers
Scenario inspired from the French RT 2012 and the Swiss SIA2024. Adapted according to our experience

occ_4r_apartment_week

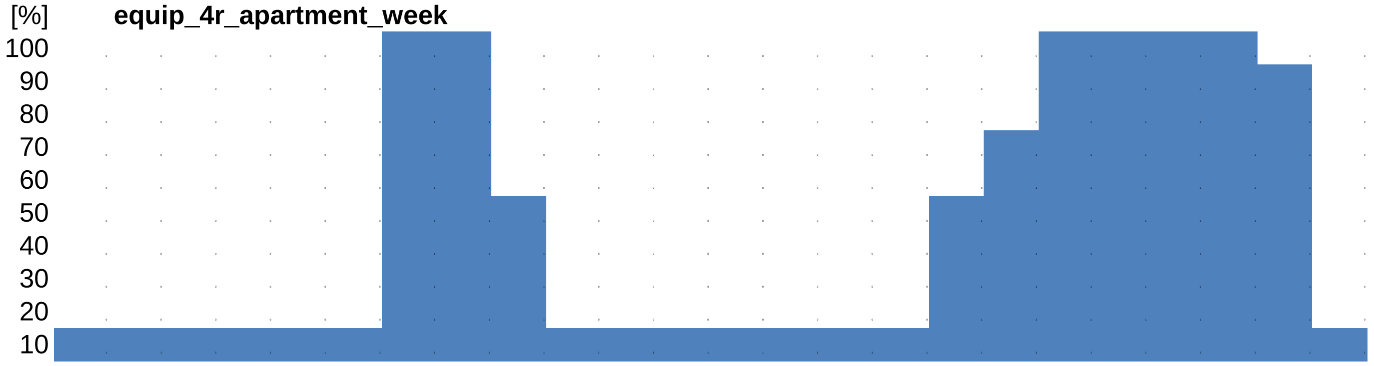


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	70	70	70	70	70	70	100	100	50	0	0	0	0	0	0	0	50	75	100	100	100	100	90	70

occ_4r_apartment_weekend

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	70	70	70	70	70	70	70	80	100	80	60	60	100	100	80	60	60	60	80	100	100	100	80	70

equip_4r_apartment_week

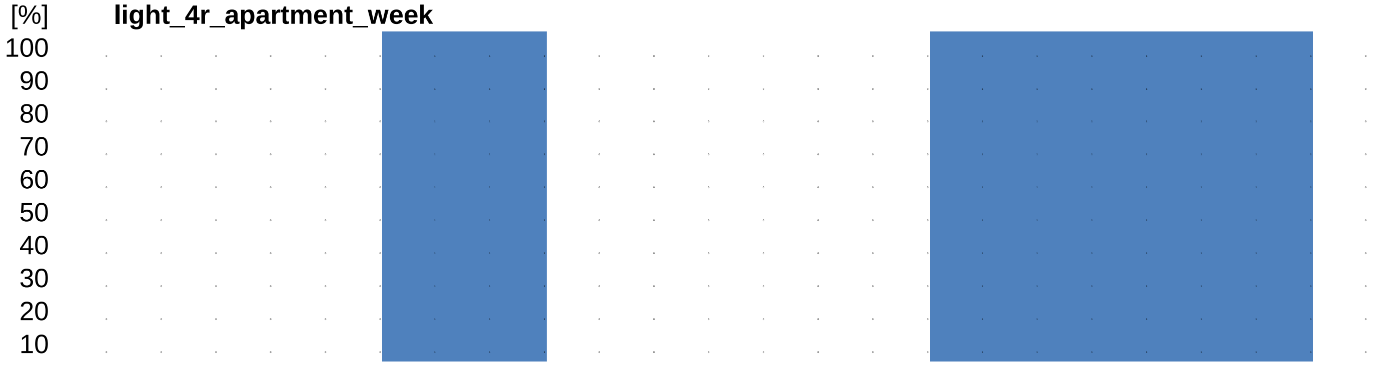


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	10	10	10	10	10	10	100	100	50	10	10	10	10	10	10	10	50	75	100	100	100	100	90	10

equip_4r_apartment_weekend

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	10	10	10	10	10	10	10	50	100	80	60	60	100	100	80	60	60	60	80	100	100	100	50	10

light_4r_apartment_week



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	0	0	0	0	0	0	100	100	100	0	0	0	0	0	0	0	100	100	100	100	100	100	100	0

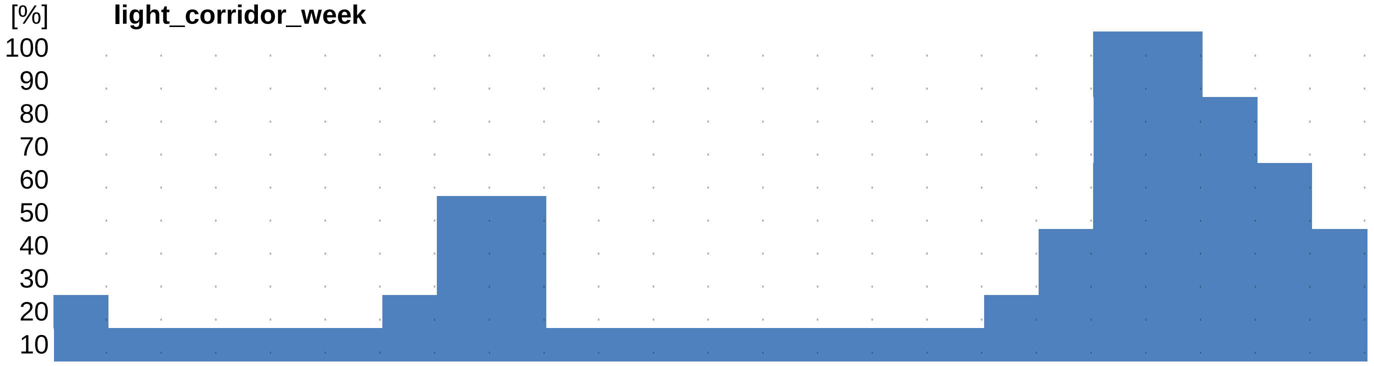
light_4r_apartment_weekend

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	0	0	0	0	0	0	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0

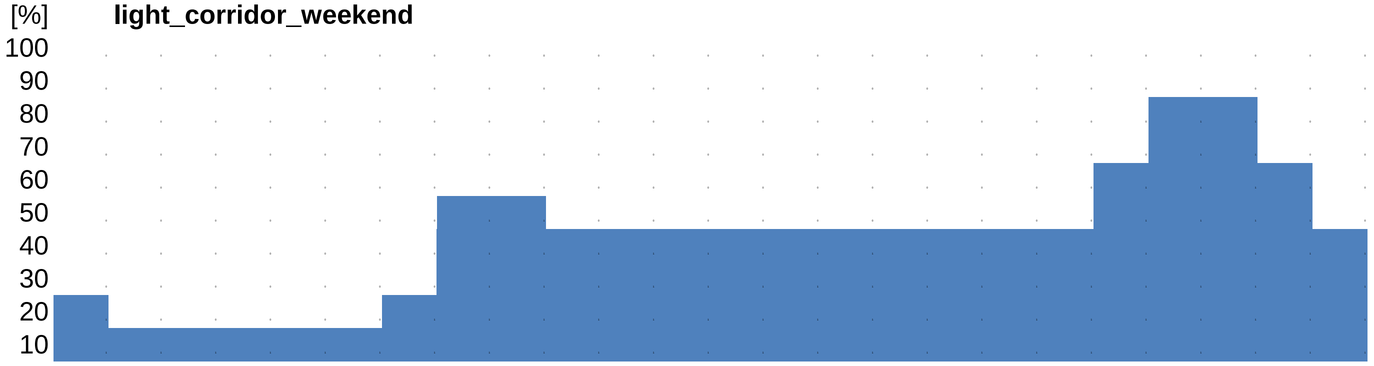
SCENARII - OCCUPATION & DOMESTIC EQUIPMENTS & ARTIFICIAL LIGHTING

All the following schedules are given without Daylight saving time (GMT +1h)

Corridor_Shared areas
Hall entrance, stairs, floor corridors
source: Enertech Study, 50 apartments in Bordeaux



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	20	10	10	10	10	10	20	50	50	10	10	10	10	10	10	10	10	20	40	100	100	80	60	40



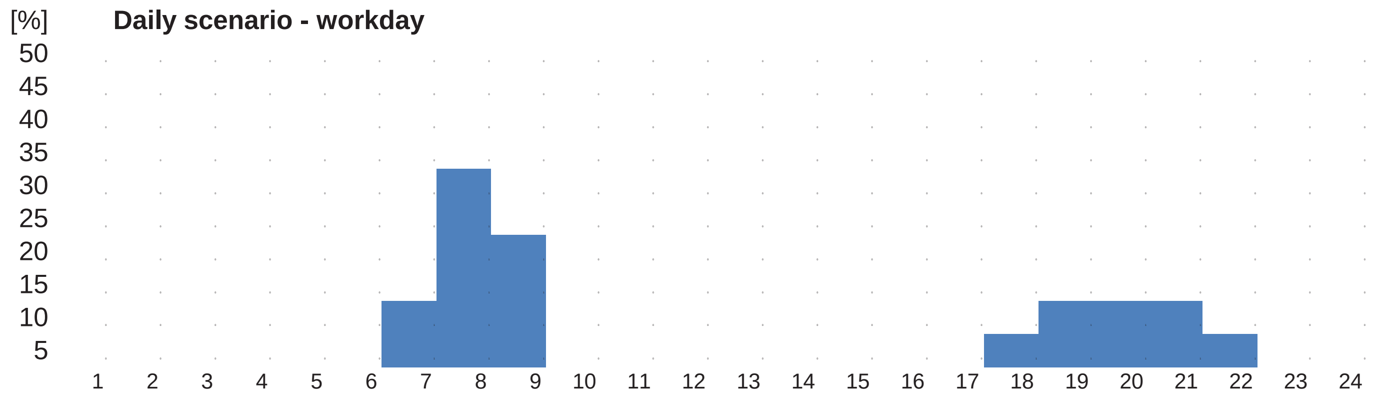
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	20	10	10	10	10	10	20	50	50	40	40	40	40	40	40	40	40	40	40	60	80	80	60	40

Boundary conditions for DHW demand

Daily DHW demand per person	50 L/pers/day	(source : Recknagel)
Outlet Temperature	40 °C	out of tap (hot water and cold water mixed)
DHW temperature from tank	57.5°C to 62.5°C	Domestic Hot Water is produced at roughly 60°C in the plant. It is then mixed with cold water to 40°C to avoid burning

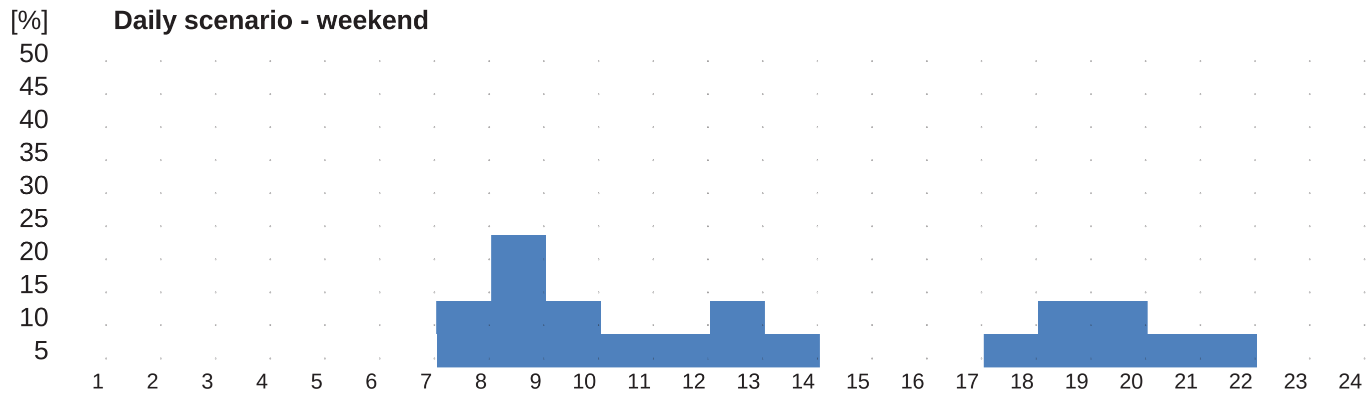
All the following schedules are given without Daylight saving time (GMT +1h)

Daily scenario - workday



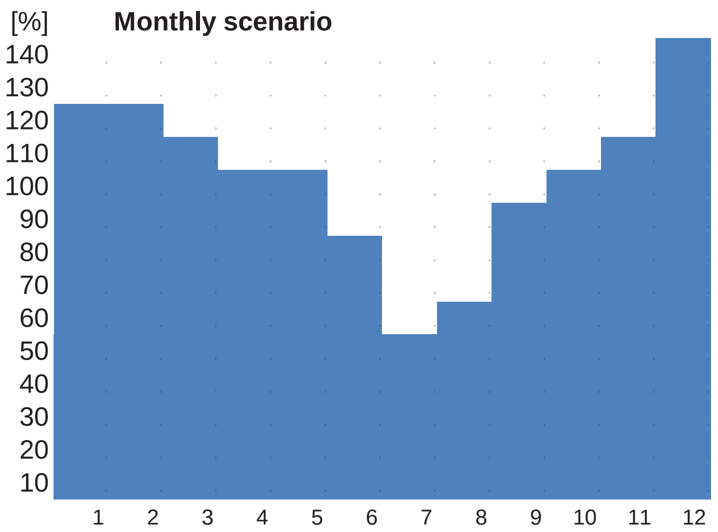
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	0	0	0	0	0	0	10	30	20	0	0	0	0	0	0	0	0	5	10	10	10	5	0	0

Daily scenario - weekend

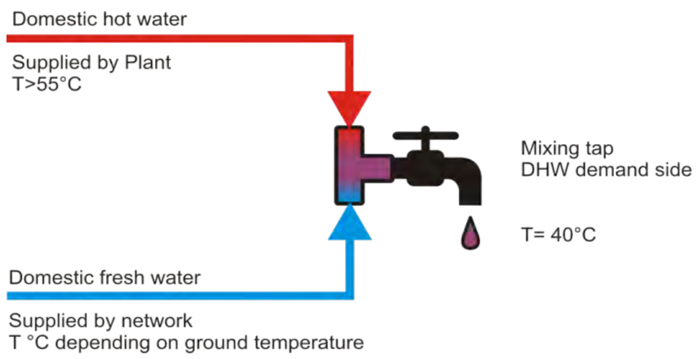


	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
[%]	0	0	0	0	0	0	0	10	20	10	5	5	10	5	0	0	0	5	10	10	5	5	0	0

Monthly scenario



	1	2	3	4	5	6	7	8	9	10	11	12
[%]	125	120	110	105	100	80	50	60	90	105	115	140



From Xpair website
http://conseils.xpair.com/consulter_savoir_faire/eau-chaude-sanitaire-bbc-rt2012/evaluation-besoins-eau-chaude-sanitaire.htm

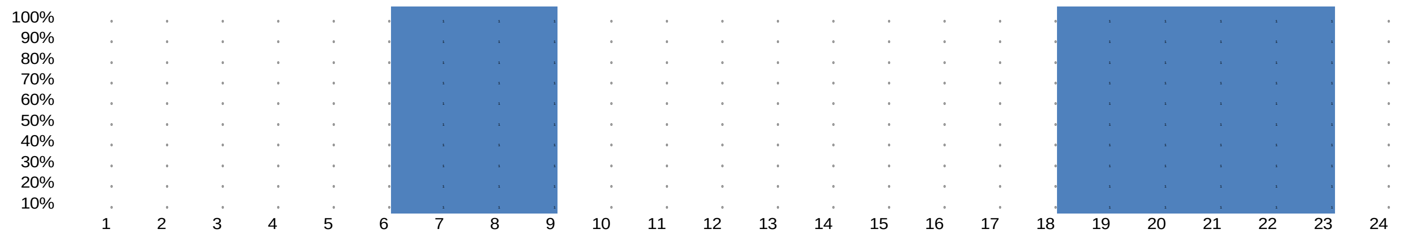
Artificial Lighting control

For the apartments

Artificial lighting is controlled according to the artificial lighting schedule and according to internal illumance estimated via a mean daylight factor for each apartment.
The apartment mean daylight factor will be calculated with a Daylight factor calculation.
With this solution, we only use artificial lighting if the schedule is superior than 0, and if natural daylight is not enough to reach the illuminance setpoint

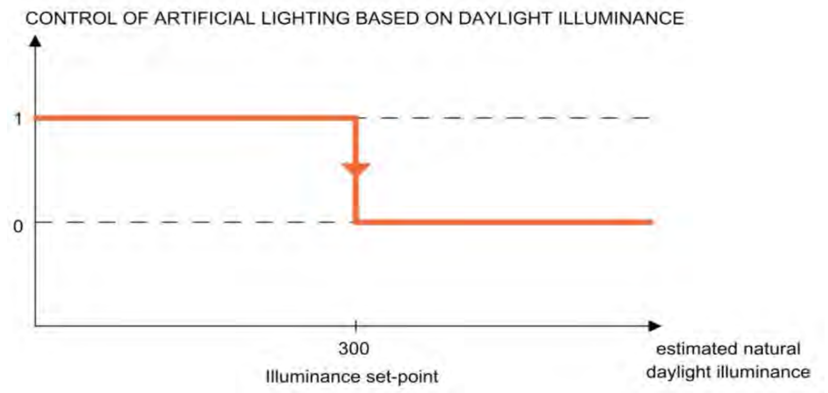
Estimated daylight illuminance	=	**Mean Daylight Factor x Horizontal illuminance on outside ground**
Horizontal illuminance on outside ground		calculated from Solar irradiation on horizontal ground from weather data file.

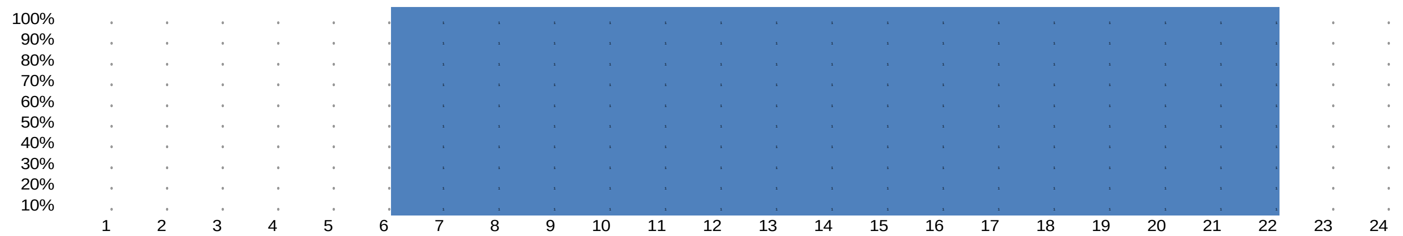
Artificial lighting is ON if artificial lighting schedule is higher than 1 and estimated daylight illuminance is lower than the set point.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
light_apartment_week	0%	0%	0%	0%	0%	0%	100%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	0%

AND



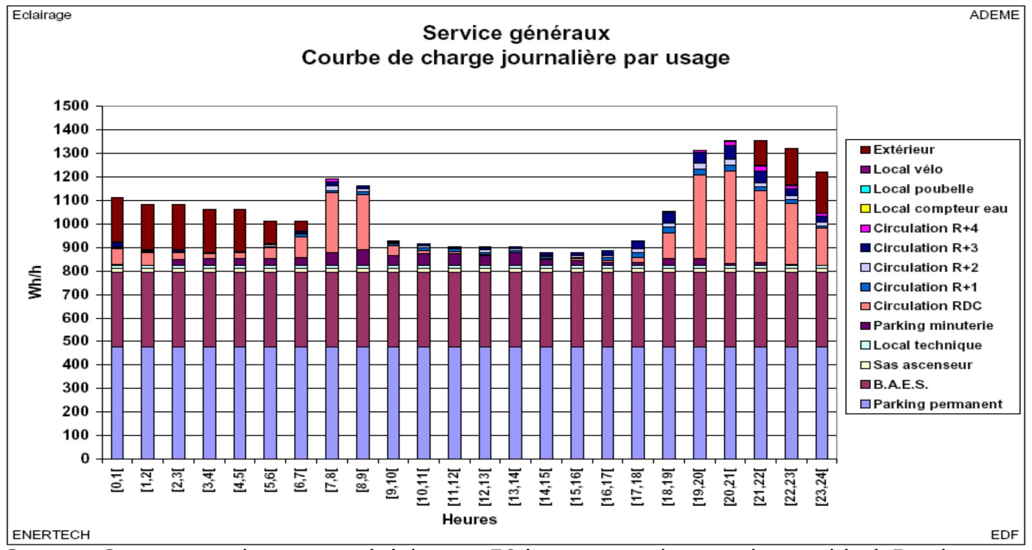


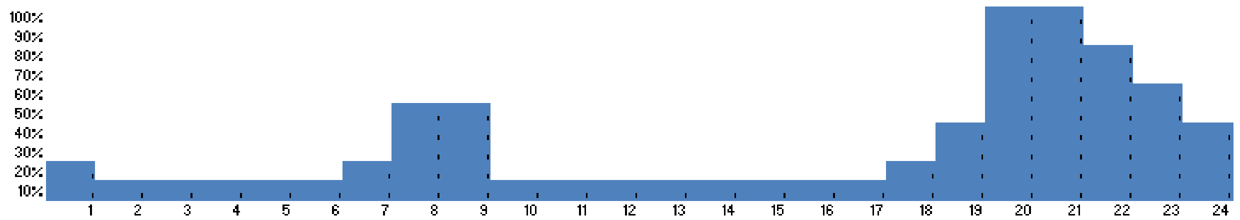
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
light_apartment_weekend	0%	0%	0%	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	0%	0%

To prevent from turning on or off all the lights in the apartment, a ratio is used to model only a part of them. Area ratio = (Living room + Bedroom) / Whole apartment = [0.7, 0.85] .
This ratio modulates the total installed lighting power.

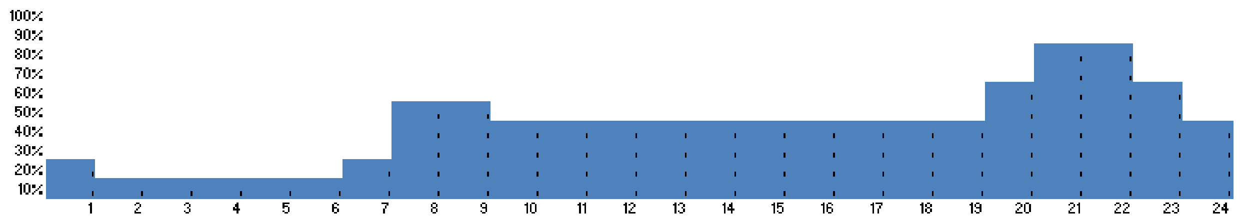
For the corridors

As the corridors are controled according to occupancy sensors, As most of the corridor area is inside the building, it does not make sense to implement a daylight control here.
Thus, we considered occupancy sensors that cut off the light when no movement is detected.
To translate that into the model, we simply considered an artifical lighting profile which tries to take into account this phenomena.
We used the results from the Enertech study to estimate a similar profile.





	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
light_corridor_week	20%	10%	10%	10%	10%	10%	20%	50%	50%	10%	10%	10%	10%	10%	10%	10%	10%	20%	40%	100%	100%	80%	60%	40%



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
light_corridor_weeker	20%	10%	10%	10%	10%	10%	20%	50%	50%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	60%	80%	80%	60%	40%

Source: Campagne de mesure éclairage : 50 logements dans un immeuble à Bordeaux et parties communes, Enertech, 2005

Setpoint Control

Control over Air Temperature

Control 0

Radiators: No control
No thermostatic valve on radiators are implemented. As a consequence, the appartment tends to overheat as there is no control on the emitters.
This phenomena is translated into TRNSYS as an increase of 2.5°C on the air temperature heating setpoint.
As a results, the heating temperature setptoint is set to 23.5°C.

Split Unit for cooling: Thermostat
The cooling device is aiming at 26°C air temperature to which is substracted a margin error of 0.5°C from the thermostat measurement process.
As a results, the cooling temperature setptoint is set to 25.5°C during the entire cooling season.

Control 1

Radiators: Night Time reduction
No thermostatic valve on radiators are implemented. As a consequence, the appartment tends to overheat as there is no control on the emitters.
This phenomena is translated into TRNSYS as an increase of 2.5°C on the air temperature heating setpoint.
Night time setpoint reduction is implemented, which is translated into a 5°C reduction during night time.
As a results, the heating temperature setptoint is set to 18.5°C between 22:00 and 06:00, and to 23.5°C otherwise.

Split Unit for cooling: Thermostat
The cooling device is aiming at 26°C air temperature to which is substracted a margin error of 0.5°C from the thermostat measurement process.
As a results, the cooling temperature setptoint is set to 25.5°C during the entire cooling season.

Control 2

Radiators: Thermostatic vale
Thermostatic valve on radiators are implemented. As a consequence, the air temperature inside the appartment is close to the temperature set point.
This phenomena is translated into TRNSYS as an increase of 0.5°C on the air temperature heating setpoint, to include a margin error on the thermostat sensor.
As a results, the heating temperature setptoint is set to 21.5°C.

Split Unit for cooling: Thermostat
The cooling device is aiming at 26°C air temperature to which is substracted a margin error of 0.5°C from the thermostat measurement process.
As a results, the cooling temperature setptoint is set to 25.5°C during the entire cooling season.

Control 3

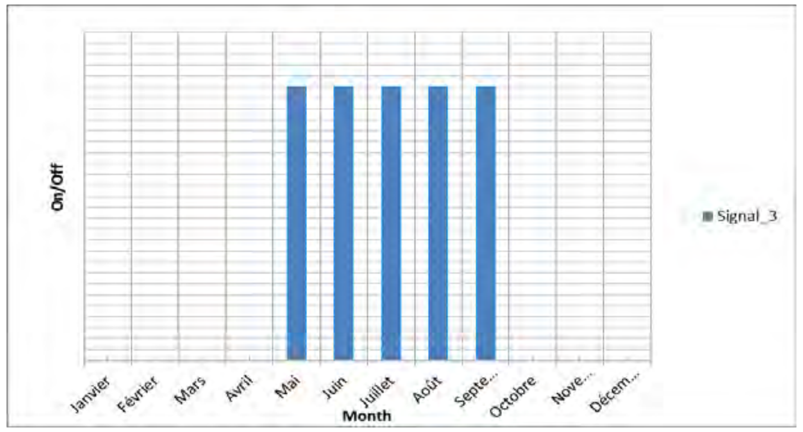
Radiators: Night Time reduction + Thermostatic valve
Thermostatic valve on radiators are implemented. As a consequence, the air temperature inside the appartment is close to the temperature set point.
This phenomena is translated into TRNSYS as an increase of 0.5°C on the air temperature heating setpoint, to include a margin error on the thermostat sensor.
Night time setpoint reduction is implemented, which is translated into a 5°C reduction during night time.
As a results, the heating temperature setptoint is set to 16.5°C between 22:00 and 06:00, and to 21.5°C otherwise.

Split Unit for cooling: Thermostat
The cooling device is aiming at 26°C air temperature to which is substracted a margin error of 0.5°C from the thermostat measurement process.
As a results, the cooling temperature setptoint is set to 25.5°C during the entire cooling season.

Shading Control

Paris & Helsinki

Shadings are closed during summer months only (Signal 3), if occupancy is higher than 0 (Signal 2), and if solar irradiation on façade is higher than 150 W/m² (Signal 1)



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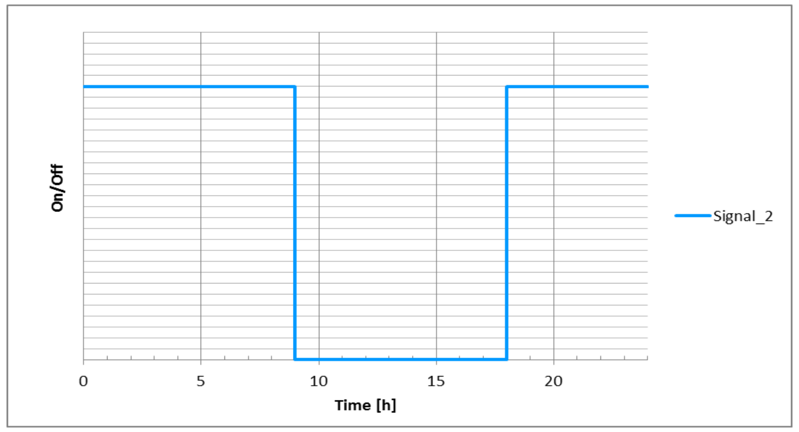

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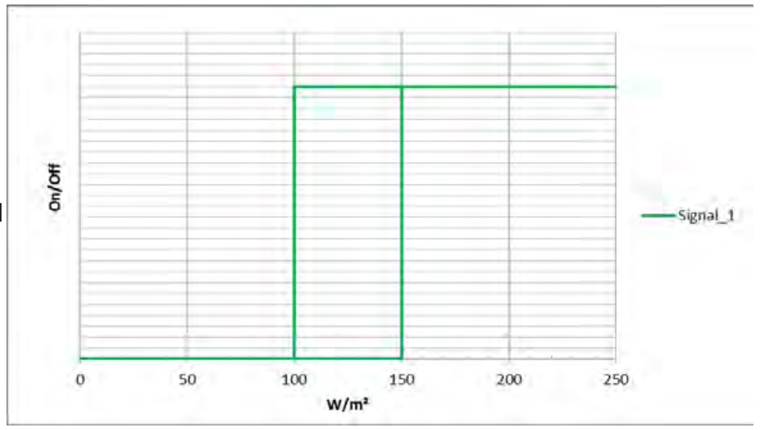
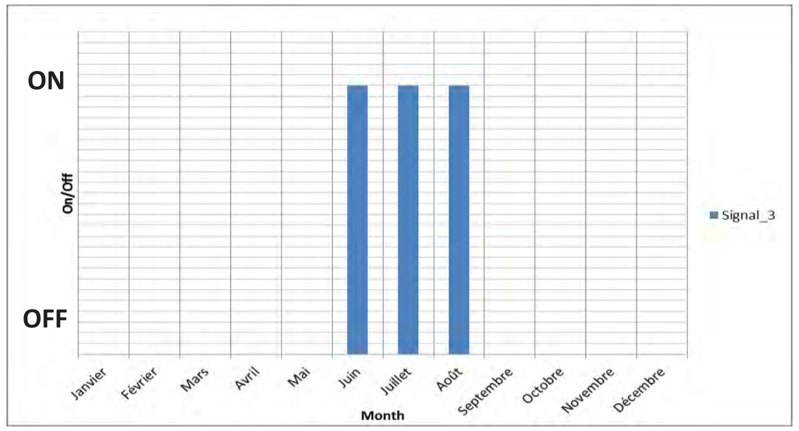


Napoli

During summer months, shading are closed during the day (Signal 3). During Winter and Shoulder Season, they ca be closed if occupancy is higher than 0 (Signal) and solar irradiation on façade is higher than 150 W/m² (Signal 1)



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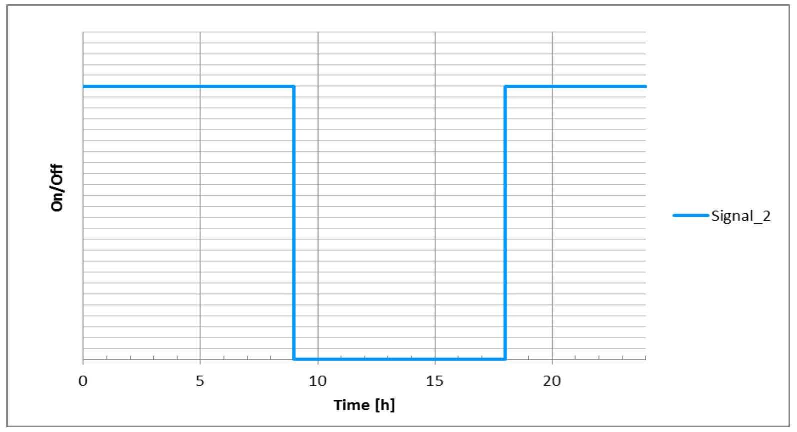

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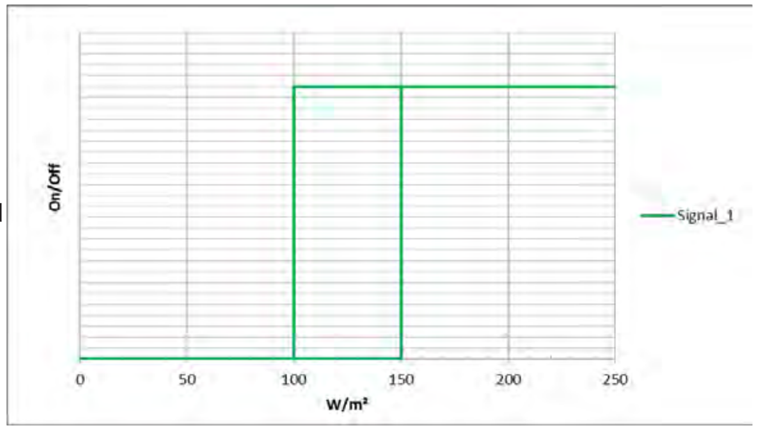
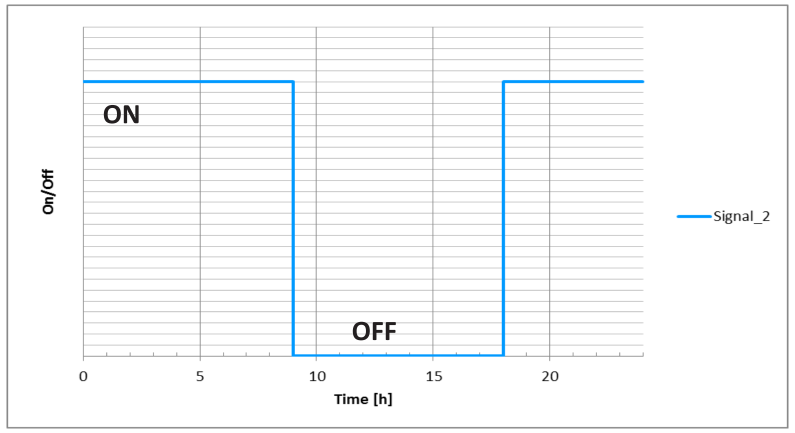


Natural Ventilation Control

Air change rate	5 vol/h	(standard value based on internal Transsolar measurements for one-sided window ventilation)

Paris, Helsinki & Napoli

During occupation (Signal 2), natural ventilation is on if outdoor temperature is lower than 23°C (Signal 1) and room temperature is higher than 23°C (hysteresis, Signal 3)



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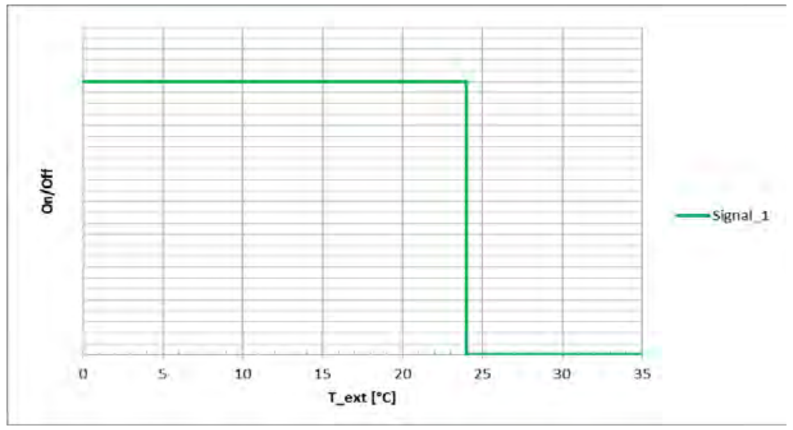

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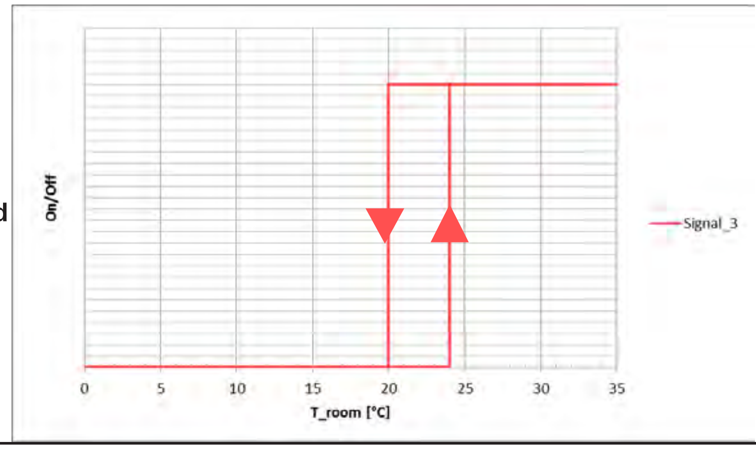


ENVELOPE

Definition of Perfomance

EXCELLENT	it represents the most stringent Regulations envisioning the perfomance that the envelope would have in 2020. it has been based and adjusted considering the values suggested by the "Passivhaus standard" and modified considering the recent Regulation for Spain and Finland and the products available on the market.
GOOD	it represents the actual Legislation available in Europe and consequently the values the new buildings need to comply with. It has been rated considering the latest German Regulation "ENEV 2016" , the French Regulation RT 2012, the Italian Regulation "DECRETO 26 giugno 2015" and the Finland one.
MEDIUM	it represents the existing building stock. The values have been based and adjusted considering the Regulation in France RT2000 and RT existant and our knowledge related to the building stock of the years 2000 -2010
LOW	it represents the old building stock before the introduction of the Regulation for the energy efficiency of the building. It has been based and adjusted considering different studies developed by the IEA (International Energy Agency) and our knowledge.

There are no considerations about the construction systems here (only thermal performances). As an example, internal or external insulation are not defined here (but are defined in the economic assessment)
This assumption is correct because thermal mass is brought to the building by the floors and the

			CLIMATE		
			Warm (Naples)	Temperate (Paris)	Cold (Helsinki)
Components	Perfomance	Unit	Value	Value	Value
WALL	EXCELLENT	U (W/m²K)	0.29	0.20	0.12
	GOOD	U (W/m²K)	0.38	0.26	0.20
	LOW	U (W/m²K)	2.75	1.52	0.93
ROOF	EXCELLENT	U (W/m²K)	0.15	0.14	0.10
		Albedo / reflexion coefficient	0.30	0.30	0.30
	GOOD	U (W/m²K)	0.36	0.20	0.14
		Albedo / reflexion coefficient	0.30	0.30	0.30
	LOW	U (W/m²K)	4.41	2.35	0.90
		Albedo / reflexion coefficient	0.30	0.30	0.30
FLOOR	EXCELLENT	U (W/m²K)	0.36	0.18	0.14
	GOOD	U (W/m²K)	0.40	0.32	0.26
	LOW	U (W/m²K)	3.37	2.02	0.90

Glossary

Parameters	Unit	Description
U wall	W/m²K	the amount of heat flowing in one second through a 1 m² of area of a building component subject to a temperature difference of 1K. It is calculated considering the Internal and External Heat Transert Resistance with the heat flowing horizontally.
U roof	W/m²K	the amount of heat flowing in one second through a 1 m² of area of a building component subject to a temperature difference of 1K. It is calculated considering the Internal and External Heat Transert Resistance with the heat flowing upwards.
U floor	W/m²K	the amount of heat flowing in one second through a 1 m² of area of a building component subject to a temperature difference of 1K. It is calculated considering the Internal and External Heat Transert Resistance with the heat flowing downards.

Components	Perfomance	Unit	CLIMATE: Warm (Naples)	CLIMATE: Temperate (Paris)	CLIMATE: Cold (Helsinki)
			Value	Value	Value
WINDOWS	EXCELLENT	Ug (W/m²K)	0.99	0.81	0.61
		Uw (W/m²K)	1.3	1.10	0.9
		g tot (glazing + moveable solar protection)	0.07	0.09	0.09
		gvalue (only glazing)	0.26	0.3	0.5
		visual transmittance VT	0.43	0.42	0.7
	GOOD	Ug (W/m²K)	1.27	1.07	1.08
		Uw (W/m²K)	1.8	1.5	1.3
		g tot (glazing + moveable solar protection)	0.15	0.15	0.15
		gvalue (only glazing)	0.33	0.53	0.65
		visual transmittance VT	0.41	0.7	0.77
	LOW	Ug (W/m²K)	5.62	5.62	2.58
		Uw (W/m²K)	5.8	5.8	2.7
		g tot (glazing + moveable solar protection)	0.3	0.5	0.5
		gvalue (only glazing)	0.89	0.89	0.64
		visual transmittance VT	0.87	0.87	0.65
AIR TIGHTNESS	EXCELLENT	n50 (ach)	0.6	0.6	0.6
	GOOD	n50 (ach)	1.5	1.5	1.5
	LOW	n50 (ach)	6	6	6
THERMAL BRIDGE CORR.	EXCELLENT	delta U (W/m²K)	0.05	0.05	0.05
	GOOD	delta U (W/m²K)	0.15	0.1	0.1
	LOW	delta U (W/m²K)	>0.2	>0.2	>0.2
VENTILATION	EXCELLENT	efficiency	80%	84%	88%
		electric power consumption (Wh/m³)	0.37	0.45	0.45
	GOOD	efficiency	0%	0%	80%
		electric power consumption (Wh/m³)	0.20	0.20	0.45
	LOW	efficiency	0%	0%	0%
		electric power consumption (Wh/m³)	0.25	0.25	0.25

Glossary

Parameters	Unit	Description
Albedo Reflexion Coefficient	%	the ratio of the reflected radiation to incident one. It can be measured in a scale from zero for no reflection (all radiation is absorbed by a black surface) to 1 for perfect reflection (all radiation is reflected by a white surface)
Ug	W/m²K	the amount of heat flowing in one second through a 1 m² of area of a transparent component subject to a temperature difference of 1K. It is fonction of the emissivity of the coatings, distance between panes and type of filling.
Uw	W/m²K	the amount of heat flowing in one second trhough a 1 m² of window component. It combines the thermal trasmittance of the glazing and the frame as well as the linear thermal transmittance from the glass edge.
visual transmittance	%	it represents the total amount of visible light passing through the transparent component.
g tot (glazing and solar protection)	%	it represents the total amount of energy transmittance reduced by the reduction factor of the solar screening.
Air tightness	n50 (ach)	it represents the Air - Leakage through 1 m² of envelope per hour. It is measured at 50 Pascals diffrential pressure.
Thermal Bridge Correction	W/m²K	it represents the value that will be added to the U of building component in order to take into account the correction of the thermal bridge. The thermal bridge represents a higher heat flow through the envelope due to a discontinuity of the insulation.It considers a
Efficiency	%	it represents the process of exchanging the energy contained in the exhausted air using it to pre treat the incoming outdoor air. It represents the percentage of heat that could be recovered.
Electric Power Consumption	Wh/m²	it represents the average power consumption of the device including regulation

PLANT MODELING

Summary

Heating		**Cooling**
Production	**Distribution**	**Production & Distribution**
Low Efficiency Gas Boiler	80°C/60°C temperature regime	Decentralized Low Efficiency Split unit
High Efficiency Gas Boiler	50°C/30°C temperature regime	Decentralized High Efficiency Split unit

NB : for the Helsinki climate, no cooling system will be implemented.

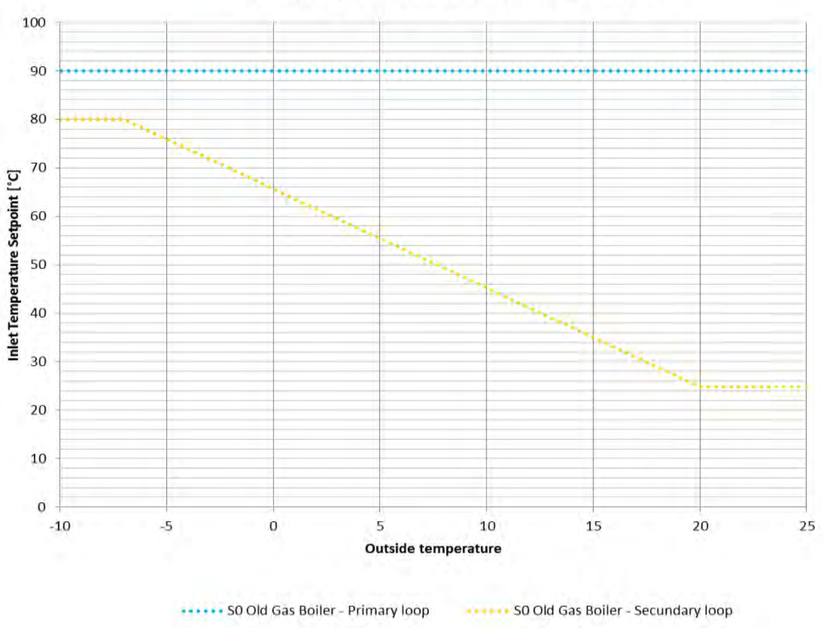
Gas Boiler - Low Efficiency Gas Boiler

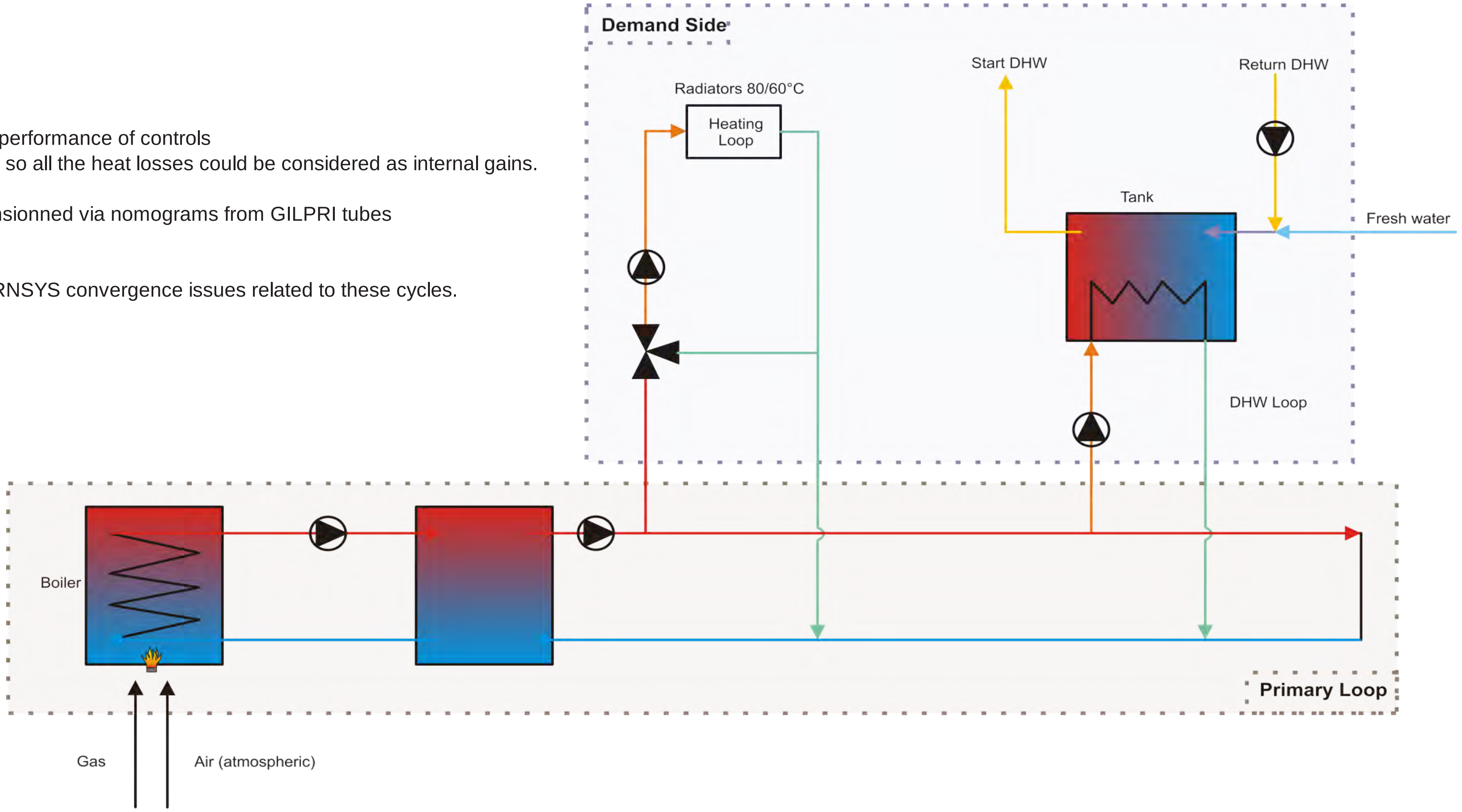
Burner	1 stage burner
Rated efficiency (80°C/60°C)	90%
Efficiency 30% Load	-
Standby losses	1.50%
Ambient losses	2%
Primary loop T°C control	constant temperature 90°C
Secondary loop T°C control	heating curve according to outside temperature

Distribution

Secondary loop	No thermal losses to prevent from lowering the performance of controls Secondary loop is located in the heated volume so all the heat losses could be considered as internal gains.
Primary loop	3 cm insulation (lambda = 0.04W/mK) for pipes Diameters depending on massflow rates, dimensionned via nomograms from GILPRI tubes Flow speed : 0.8m/s

A tank storage is implemented between boiler and primary loop.
This buffer tank helps to reduce the ON/OFF boiler cycling and solve some TRNSYS convergence issues related to these cycles.





Cooling with decentralized Split Units - Base variant

Decentralized Low Efficiency Split unit

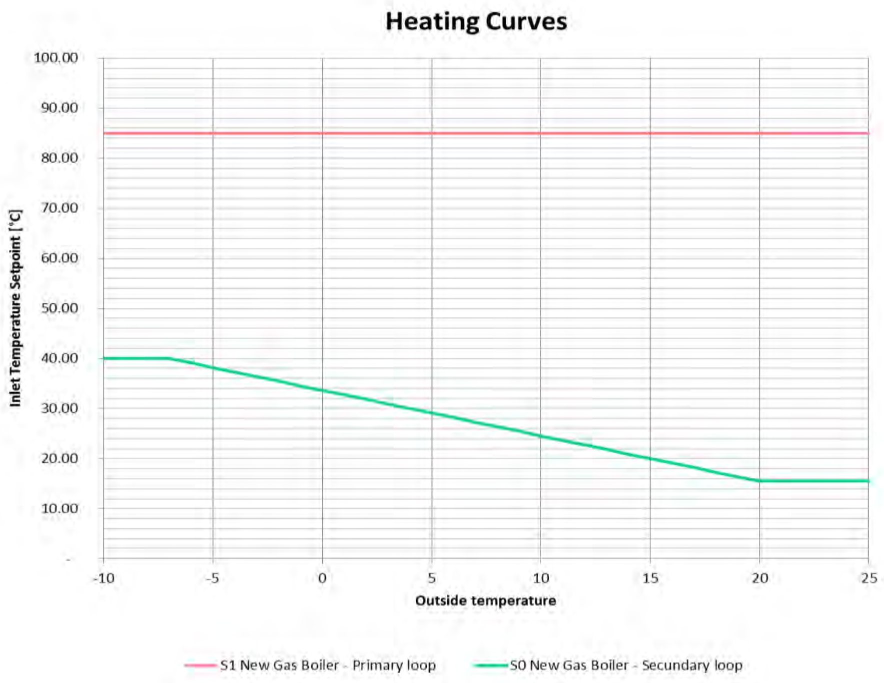
EER	1.9
SEER	2.7

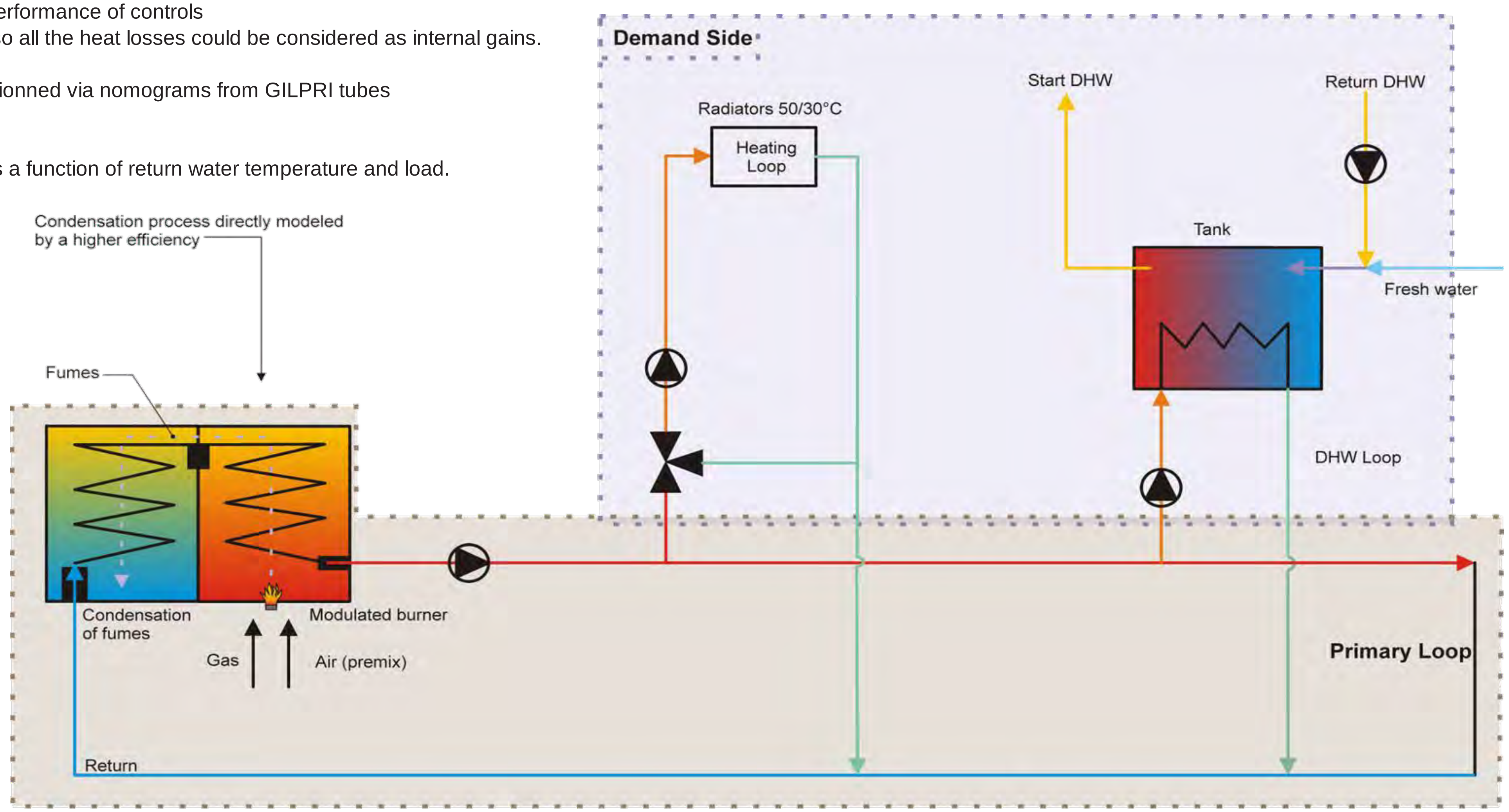
Gas Boiler - High Efficiency Gas Condensation Boiler	
Burner	Moduling 10%-100% Burner
Rated efficiency (80°C/60°C)	97.5%
Efficiency 30% Load	108.5%
Standby losses	0.10%
Ambient losses	1.0%
Primary loop temperature con	constant temperature 85°C
Secondary loop temperature (	heating curve according to outside temperature

Distribution

Secondary loop	No thermal losses to prevent from lowering the performance of controls
	Secondary loop is located in the heated volume so all the heat losses could be considered as internal gains.
Primary loop	3 cm insulation (lambda = 0.04W/mK) for pipes
	Diameters depending on massflow rates, dimensionned via nomograms from GILPRI tubes
	Flow speed : 0.8m/s

No convergence issues, the boiler burner is adapting itself to network load.
Condensing boiler is modeled as a classic boiler with an efficiency calculated as a function of return water temperature and load.
Efficiency can then be higher than 100%, when calculated with HHV.





Cooling with decentralized Split Units - Improved

Decentralized High Efficiency Split unit

EER	3.5
SEER	5.7

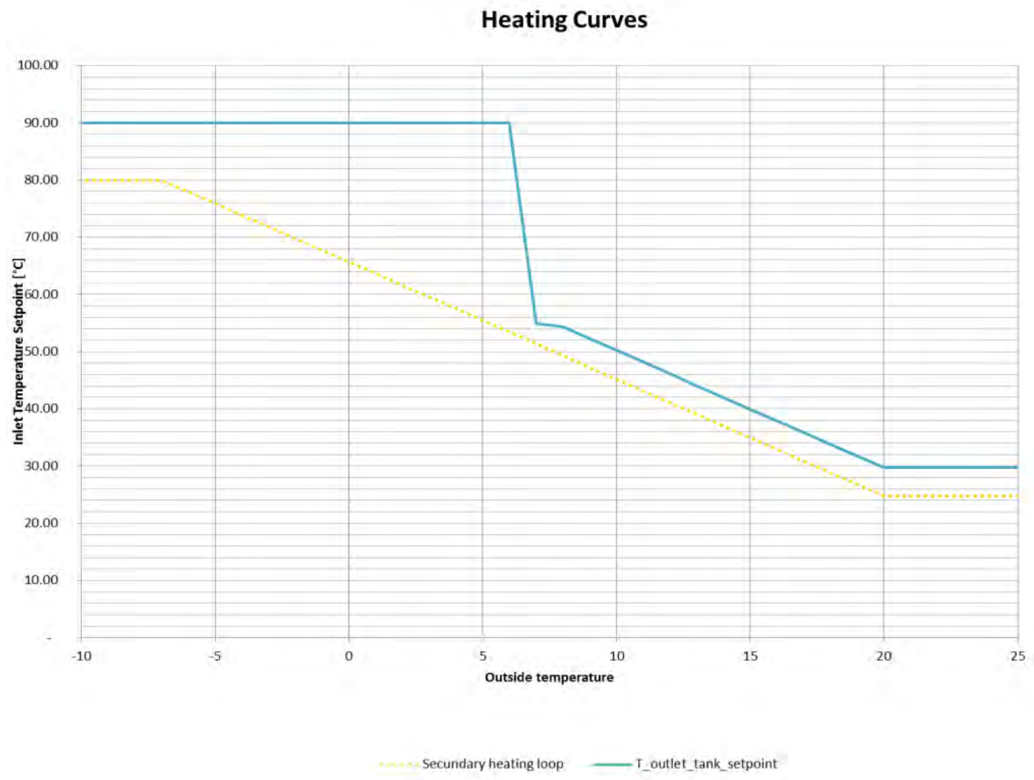
Air to Water Heat Pump + Old Boiler for DHW and temperatures below 7°C

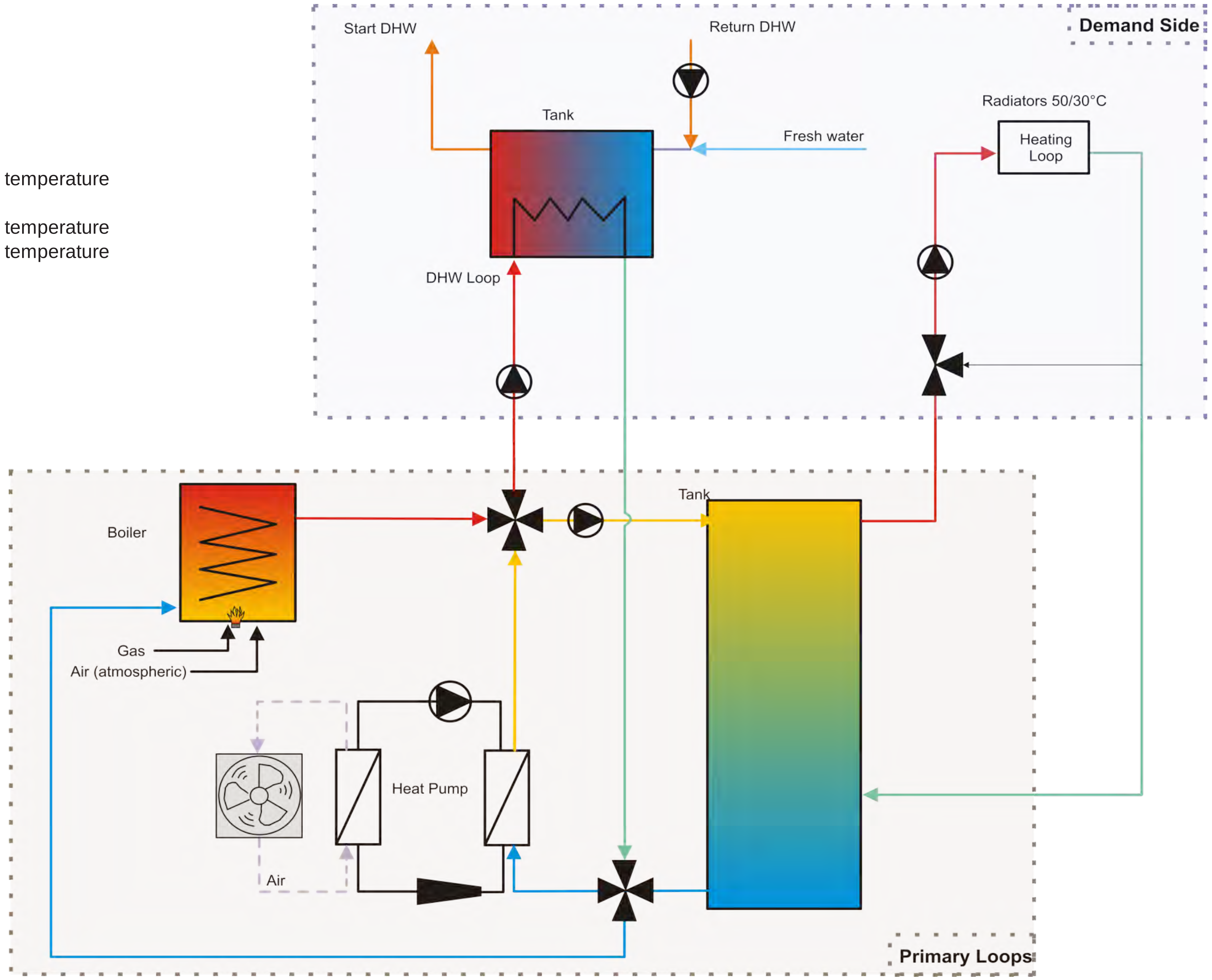
Air to Water Heat Pump

Heat Pump COP	2.99	(45°C/40°C regime with 7°C outside air temperature)
Bivalent temperature	7	°C

Gas Boiler - Low Efficiency Gas Boiler

Burner 1 stage burner		
Rated efficiency (80°C/60°C)	90%	
Efficiency 30% Load	-	
Standby losses	1.50%	
Ambient losses	2%	
Primary loop T°C control		constant temperature 90°C
Secondary loop T°C control		heating curve according to outside temperature
Primary loop temperature control		heating curve according to outside temperature
Secondary loop temperature control		heating curve according to outside temperature





Cooling with decentralized Split Units - Improved

Decentralized High Efficiency Split unit

EER	3.5
SEER	5.7

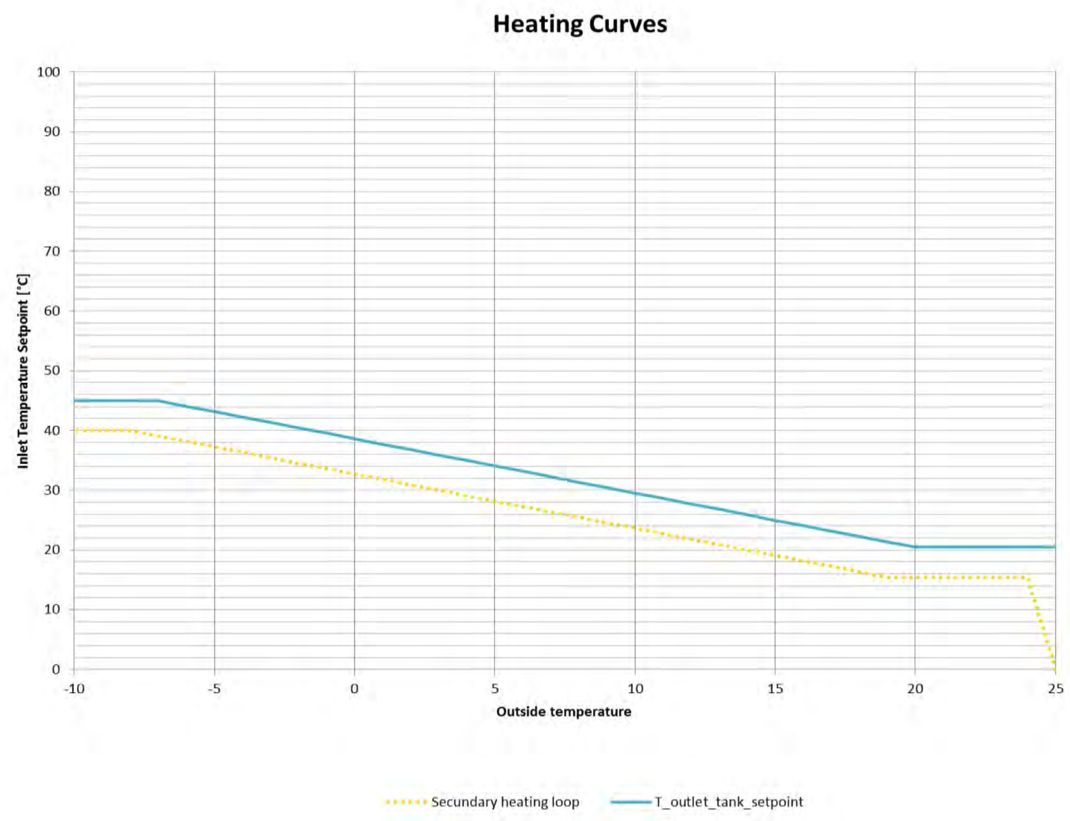
Air to Water Heat Pump + Old Boiler for DHW only

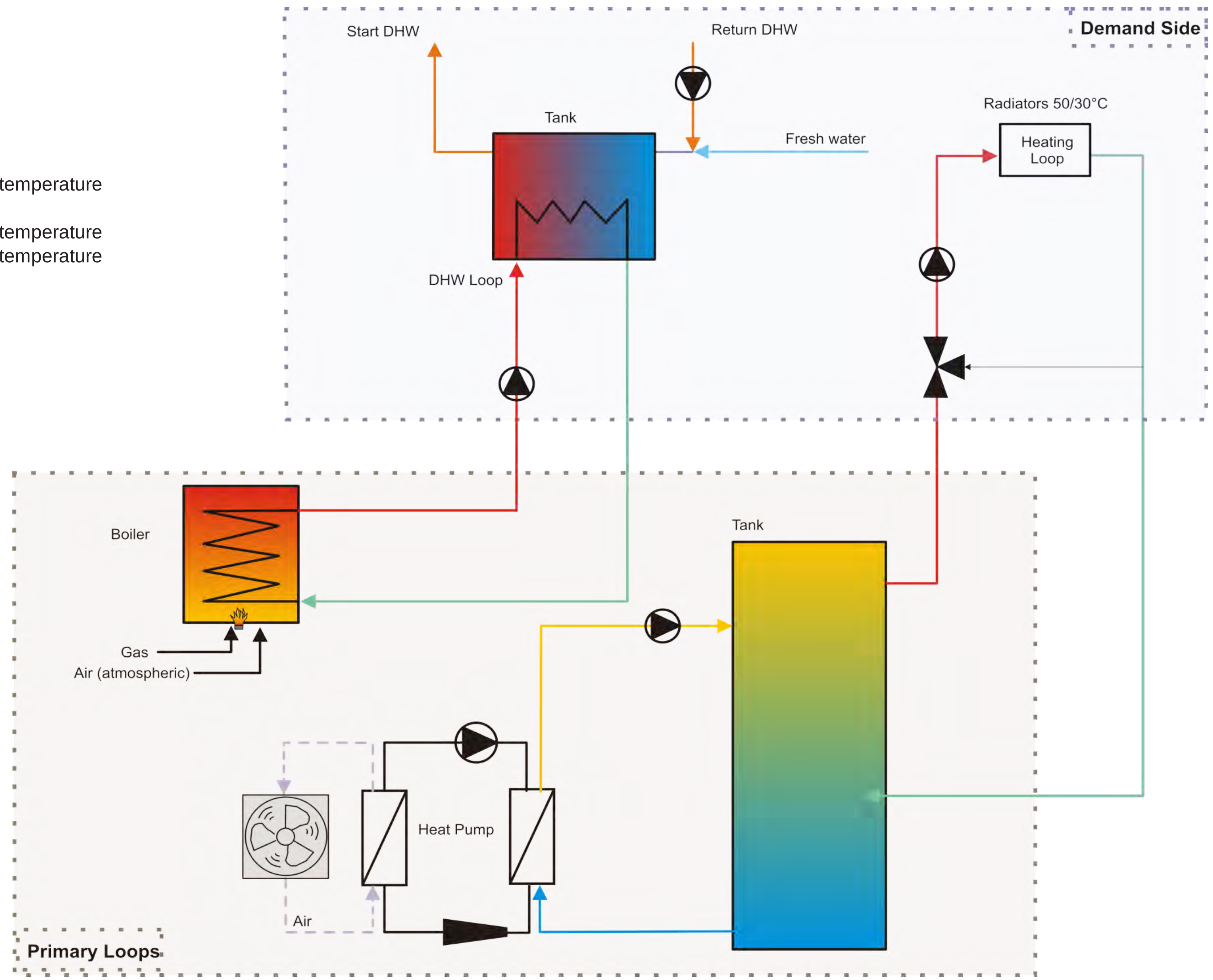
Air to Water Heat Pump

Heat Pump COP	2.99	(45°C/40°C regime with 7°C outside air temperature)
Bivalent temperature	No bivalence	

Gas Boiler - Low Efficiency Gas Boiler

Burner	1 stage burner	
Rated efficiency (80°C/60°C)	90%	
Efficiency 30% Load	-	
Standby losses	1.50%	
Ambient losses	2%	
Primary loop T°C control		constant temperature 90°C
Secondary loop T°C control		heating curve according to outside temperature
Primary loop temperature control		heating curve according to outside temperature
Secondary loop temperature control		heating curve according to outside temperature





Cooling with decentralized Split Units - Improved

Decentralized High Efficiency Split unit

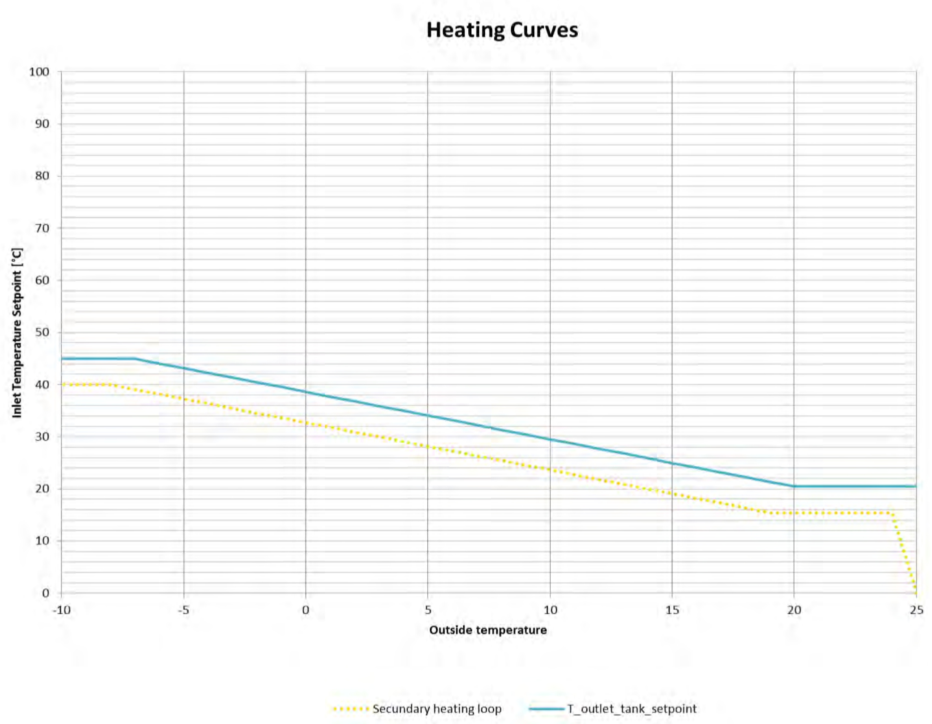
EER	3.5
SEER	5.7

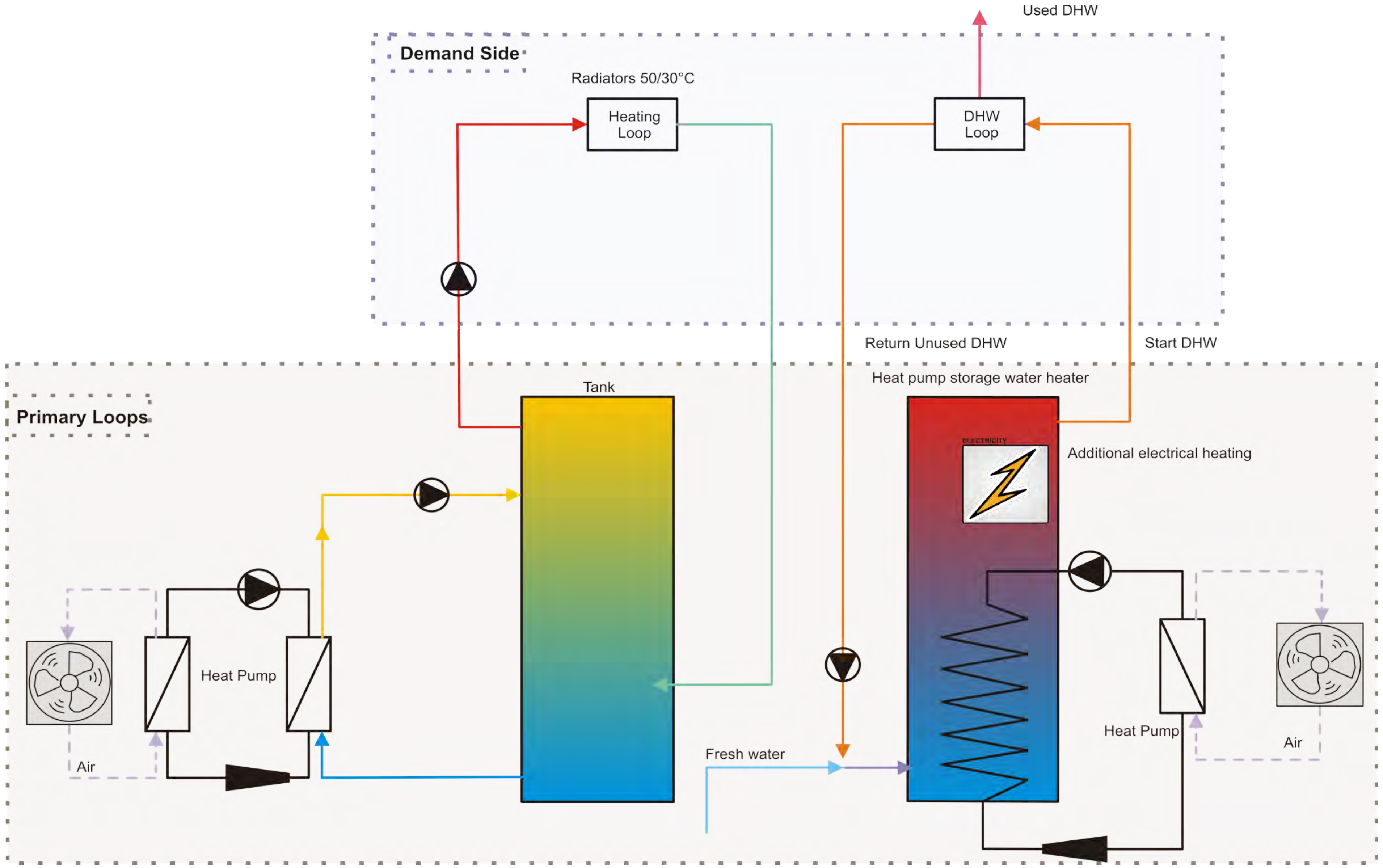
Air to Water Heat Pump + Heat Pump Storage Water Heater with additional electrical resistance for DHW

Air to Water Heat Pump

Heat Pump COP	4	(35°C/30°C regime with 7°C outside air temperature)
Heat Pump COP DHW	2.5	(7°C/55°C regime with 7°C outside air temperature)

Primary loop temperature control	heating curve according to outside temperature
Secondary loop temperature control	heating curve according to outside temperature





Cooling with decentralized Split Units - Improved

Decentralized High Efficiency Split unit

EER	3.5
SEER	5.7

6. ANNEX III: Tribu Energie Report

TRIBU ENERGIE
Toute notre énergie pour 4 fois moins de CO_2

Heating and Cooling Research
Economic study

Eurima

Study report

Project director	Nathalie Tchang	Date	2017-01-02
Project manager	-	Report reference	ET16-105
		Version	6
Project engineer	Nicolas Desmars	Phase	-
Diffusion	EURIMA		

Membre fondateur de Pacte Ingénierie

Qualification RGE OPQIBI L'INGÉNIERIE QUALIFIÉE Efficacité énergétique ENR

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Report monitoring

File name	File date	Version number	Modifications
TE-160729-ND-16-105-Eurima economic study	29 July 2016	1	/
TE-160823-NDNT-16-105-Eurima economic study	23 August 2016	2	Integration of Finland and Italy cases Wording and page setting modifications
TE-161010-NDNT-16-105-Eurima economic study	10 October 2016	3	Deletion of the internal wall insulation case (1bis) No investment in split units in case 2 bis Integration of heat pump cases Results per m²
TE-161013-NDNT-16-105-Eurima economic study	13 October 2016	4	Investment in split units in case 1 ter Wording and page setting modifications
TE-161026-NDNT-16-105-Eurima economic study	26 October 2016	5	Modification of the electrical final energy consumptions (taken from the latest version of the Transsolar study) Wording modifications
TE-170102-NDNT-16-105-Eurima economic study	2 January 2017	6	Wording modifications

Table of contents

1 Introduction

1.1 Background and content of the study

The Energy Performance of Building Directives (EPBD) revision causes an increased competition between active and passive technologies. In order to raise the understanding of the respective contribution of both technologies, a detailed thermal study has been fulfilled by Transsolar. The aim of this economic study is to complete Transsolar's study in order to figure out the economic impacts of different improvement potentials of the renovation of a building. The analysis covers energy costs, investment costs and maintenance costs over a 50 years span. The costs engendered by different levels of energy efficiency improvements have been calculated for different cases in three European countries.

The following improvement cases have been studied:

Base case (economic)	Low envelope Night time reduction Old boiler - 1 speed burner Plant sized following the low envelope demand Split unit for cooling (low efficiency)
Case 1	Low envelope Night time reduction, **thermostat on radiators** Old boiler - 1 speed burner Plant sized following the low envelope demand Split unit for cooling (low efficiency)
Case 1 bis (economic)	**Good envelope** Night time reduction Old boiler - 1 speed burner Plant sized following the low envelope demand Split unit for cooling (low efficiency)
Case 1 ter (economic)	Low envelope Night time reduction **New condensing boiler - modulating burner** Plant sized following the low envelope demand **Split unit for cooling (high efficiency)**
Case 1 ter HP (economic)	Low envelope Night time reduction Old boiler - 1 speed burner **Heat pump** **Split unit for cooling (high efficiency)**
Case 2	**Good envelope** Night time reduction, **thermostat on radiators** **New condensing boiler - modulating burner** **Plant sized following the good envelope demand** Split unit for cooling (low efficiency)
Case 2 HP	**Good envelope** Night time reduction, **thermostat on radiators** **Heat pumps (heating and domestic hot water)** Split unit for cooling (low efficiency)
Case 2 bis	**Good envelope** Night time reduction **New condensing boiler - modulating burner** **Plant sized following the good envelope demand** Split unit for cooling (low efficiency)
Case 2 ter	**Good envelope** Night time reduction, **thermostat on radiators** **New condensing boiler - modulating burner** Plant sized following the low envelope demand **Split unit for cooling (high efficiency)**

Case 2 ter HP	**Good envelope** Night time reduction, **thermostat on radiators** **New condensing boiler - modulating burner** **Heat pump** **Split unit for cooling (high efficiency)**
Case 3	**Excellent envelope** Night time reduction, **thermostat on radiators** **New condensing boiler - modulating burner** **Plant sized following the excellent envelope demand** **Split unit for cooling (high efficiency)**

Two scenarios have been studied, in order to take into account two different possibilities for the cases which include the "New condensing boiler – modulating burner" or "heat pump" improvement:

- only the replacement of the boiler (or heat pump) ;
- replacement of the boiler (or heat pump) and global plant refurbishment (replacement and insulation of the pipes, replacement of the heating and hot water pumps and valves).

The following countries/climates have been studied:

- France (Paris) – detailed study ;
- Finland (Helsinki) ;
- Italy (Napoli).

1.2 Methodology

The climates and cases detailed above are based on the technical results and hypothesis of the Transsolar study:

161020_EUR_TS_Energy__amp_Comfort_Study_v10.pdf

This economic study has selected the most representative cases. Transsolar has given us results for this specific case that does not appear in the technical report: night time reduction is "ON" for all the cases of the economic study (because a low envelope building with no night time reduction isn't realistic).

The final energy consumptions taken to calculate the annual energy costs come from the Transsolar study. The improvement works and maintenance costs are based on average prices in France and have been adapted for the other European countries by using official European statistics. The sources of the hypothesis taken for the determining of the costs for each country (energy, maintenance, improvement works) are detailed in the Annex of this report.

2 Detailed Results – France (Paris)

The Transsolar study includes several cases with the replacement of the old boiler by a new condensing boiler (and/or a heat pump). This replacement is in reality often combined with a global plant refurbishment (replacement and insulation of the pipes, replacement of the heating and hot water pumps and valves).

This is why in order to be more realistic, two scenarios have been studied:

- "Boiler only" replacement scenario ;
- Global plant refurbishment scenario.

On the graphs, the influence of the lifespan of the new systems (cases 1 to 3) has been taken into account. The new systems are replaced every 23 years (average new system lifespan). This can be viewed on the following graphs.

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2.1 "Boiler only" replacement scenario

		Final energy consumption (kWhFE/m²/y)		Improvement cost (€/m² including taxes)	Annual operating cost (€/m² including taxes/y)	Percentage gain on operating costs (%)	Return on investment with a 2%/y energy price increase (y)	Return on investment with a 4%/y energy price increase (y)	Annual energy cost - year 1 - (€/m² including taxes/y)	Annual maintenance cost - year 1 - (€/m² including taxes/y)	Maintenance cost percentage on total operating costs - year 1 - (%)
		Gas	Electricity								
Base case (technical)	*Low envelope* *No control* *Old boiler - 1 speed burner* *Plant sized following the low envelope demand* *Split unit for cooling (low efficiency)*	*419*	*36*	*-*	*27*	*-*	*-*	*-*	*26*	*1*	*4%*
Base case (economic)	Low envelope Night time reduction Old boiler - 1 speed burner Plant sized following the low envelope demand Split unit for cooling (low efficiency)	375	33	-	26	-	-	-	25	1	4%
Case 1	Low envelope Night time reduction, **thermostat on radiators** Old boiler - 1 speed burner Plant sized following the low envelope demand Split unit for cooling (low efficiency)	313	31	3	23	13%	1	1	21	1	5%
Case 1 bis (economic)	**Good envelope** Night time reduction Old boiler - 1 speed burner Plant sized following the low envelope demand Split unit for cooling (low efficiency)	139	23	328	12	52%	21	18	11	1	11%
Case 1 ter (economic)	Low envelope Night time reduction **New condensing boiler - modulating burner** Plant sized following the low envelope demand **Split unit for cooling (high efficiency)**	292	33	61	22	15%	13	12	21	1	5%
Case 1 ter HP (economic)	Low envelope Night time reduction Old boiler - 1 speed burner **Heat pump** **Split unit for cooling (high efficiency)**	221	68	101	25	5%	More than 50	43	23	2	7%
Case 2	**Good envelope** Night time reduction, **thermostat on radiators** **New condensing boiler - modulating burner** **Plant sized following the good envelope demand** Split unit for cooling (low efficiency)	70	20	385	8	68%	19	17	7	1	17%
Case 2 HP	**Good envelope** Night time reduction, **thermostat on radiators** **Heat pumps (heating and domestic hot water)** Split unit for cooling (low efficiency)	0	45	443	10	61%	27	19	7	3	26%
Case 2 bis	**Good envelope** Night time reduction **New condensing boiler - modulating burner** **Plant sized following the good envelope demand** Split unit for cooling (low efficiency)	86	21	339	9	67%	17	15	8	1	7%
Case 2 ter	**Good envelope** Night time reduction, **thermostat on radiators** **New condensing boiler - modulating burner** Plant sized following the low envelope demand **Split unit for cooling (high efficiency)**	71	20	392	9	67%	19	16	7	1	17%
Case 2 ter HP	**Good envelope** Night time reduction, **thermostat on radiators** **New condensing boiler - modulating burner** **Heat pump** **Split unit for cooling (high efficiency)**	38	40	450	11	58%	28	20	9	2	21%
Case 3	**Excellent envelope** Night time reduction, **thermostat on radiators** **New condensing boiler - modulating burner** **Plant sized following the excellent envelope demand** **Split unit for cooling (high efficiency)**	26	21	432	6	76%	17	16	5	1	23%

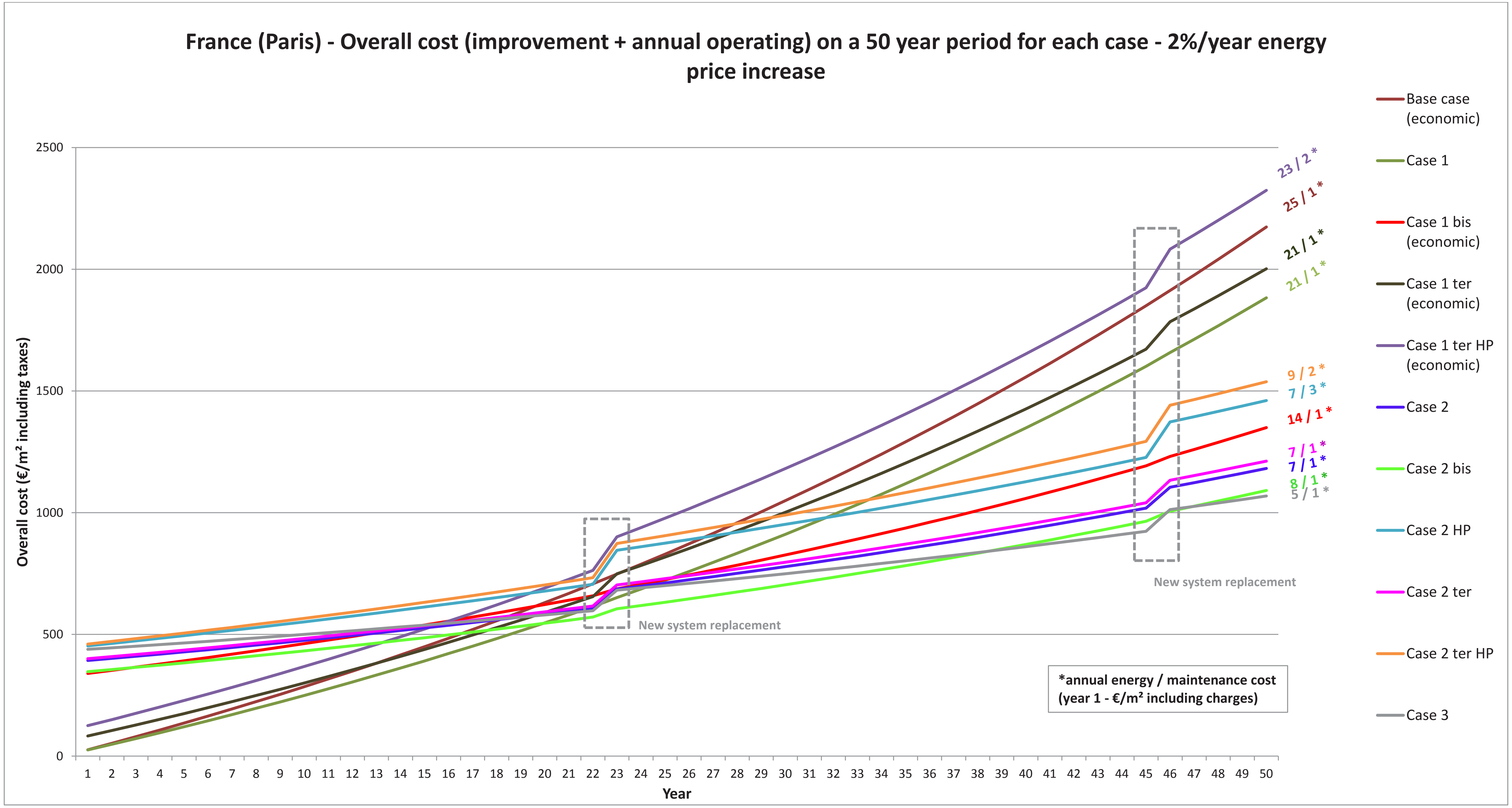
Cases 1 and 1 ter only include the replacement of components of the heating system. The investment costs for these cases are low. However, the reduction of the final energy consumption and therefore of the operating costs is limited (13% and 15%). Consequently, these improvement works are economically attractive in the short term (the return on investment is under 13 years), but less interesting on the long term (because of the low gain on operating costs).

Case 1 bis only includes the improvement of the envelope. The investment cost for this case is high, but the reduction of the final energy consumption and therefore of the operating costs is also high (52%). As a result, these improvement works are economically attractive as a medium and long term investment (the return on investment goes from 18 to 21 years) due to the high gain on operating costs.

Cases 2, 2 bis and 2 ter include both envelope and system improvements. As for case 1 bis, the investment cost for these cases is high, but the reduction of the final energy consumption and therefore of the operating costs is also high (67% and 68%). As a result, these improvement works are economically attractive as medium and long term investments (the return on investment goes from 15 to 19 years) due to the high gain on operating costs.

Case 3 is similar to cases 2, 2 bis, and 2 ter but even more attractive in the long term. The improvement costs are the highest among all the cases, but the gain on operating costs is the best within these cases.

Heat pump cases (1 ter HP, 2 HP and 2 ter HP) are not economically attractive (compared to similar cases with the new condensing boiler) because heat pump investment costs are higher than new boiler ones, and because of the high electricity and maintenance prices.



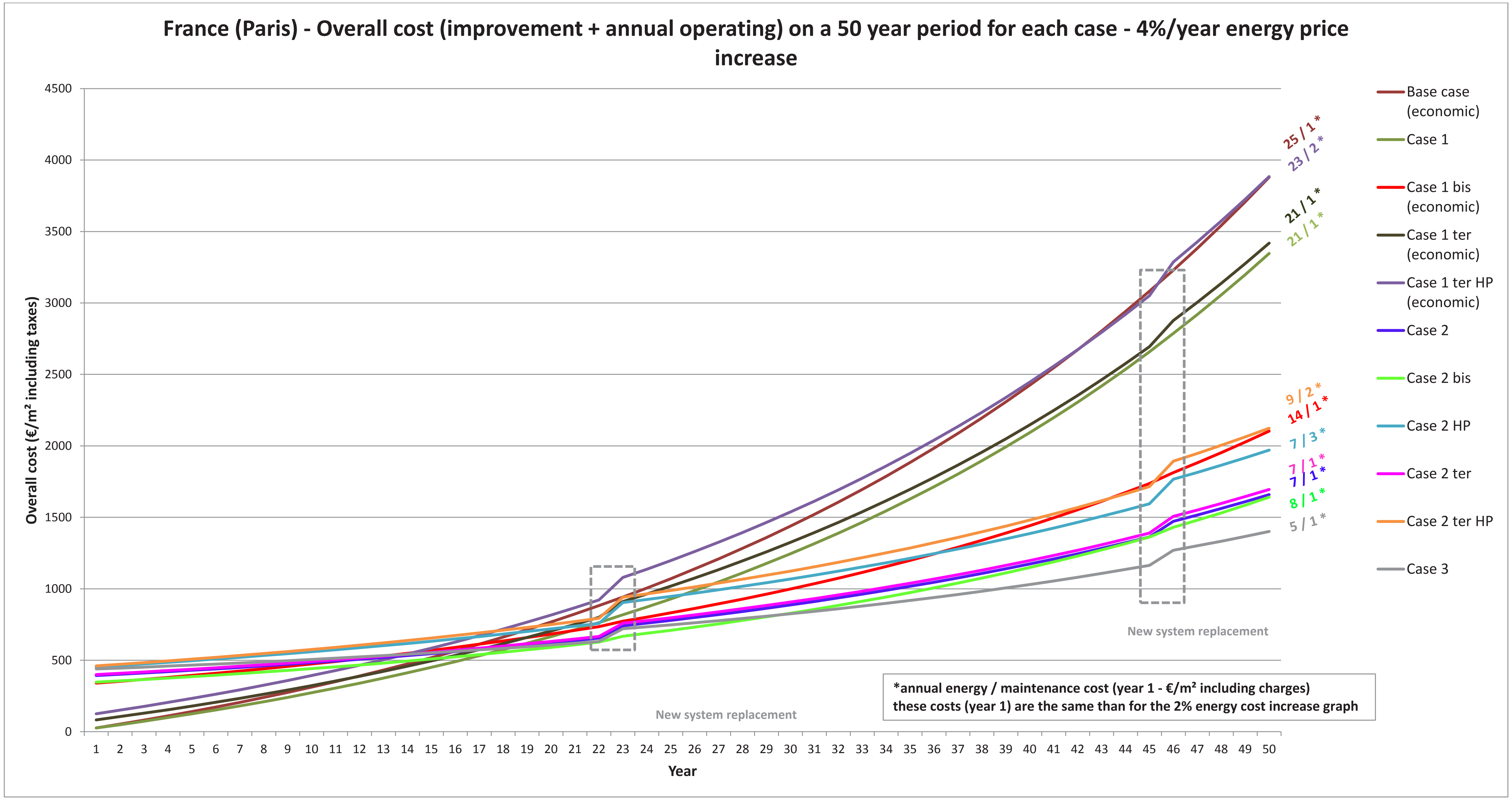
Theses curves show the overall cost for each case considering a **2% energy cost increase per year (low estimation)**. These overall cost curves reveal three different main trends depending on the case.

The first trend is the **base case**, which is the case with the highest slope (it has high operative costs: 26 €/m²/y because no improvement works have been done). It is the worst economic case in the medium and long term.

The second group of curves contains **cases 1 and 1 ter**, that only include the replacement of components of the heating system. These cases are very similar and their slope is high (they have high operative costs: 22 to 23 €/m²/y because the gain on final energy consumptions due to the improvements is low). These cases are attractive in the short term (less than 20 year), but become unattractive in the long term (more than 25/30 years).

The third group of curves contains **cases 1 bis, 2, 2bis, 2 ter and 3**. Their common trait is that they all include the improvement of the building envelope. Their slope is low (they have low operative costs: 6 to 12 €/m²/y because the gain on final energy consumptions due to the improvements – in particular the envelope insulation - is high). These cases are expensive in the short term (less than 15/20 years) because of the high investment costs, but become attractive in the medium term (20/25 years) and very attractive in the long term (more than 25 years). The only way of reducing significantly the operating and the global costs in the medium and long term is to make envelope insulation improvements. Adding performant heating and cooling systems enables to be even more economically attractive only if the building has a good or excellent envelope insulation.

Heat pump cases (1 ter HP, 2 HP and 2 ter HP) are not economically attractive (compared to similar cases with the new condensing boiler) because heat pump investment costs are higher than new boiler ones, and because of the high electricity and maintenance prices.



Theses curves show the overall cost for each case considering a **4% energy cost increase per year (high estimation)**. Compared with the previous "2% energy cost increase" graph, the main difference is the wider gap of the overall cost (which is noticeable especially in the long term) between the most energy efficient cases (1 bis, 2, 2 HP, 2 bis, 2 ter, 2 ter HP, 3) and the less energy efficient cases (base, 1, 1 ter, 1 ter HP). The returns on investment are also shorter than with a 2% energy cost increase.

In this graph, base case and case 1 ter HP are clearly the worst economic cases in the long term: base case because of its high energy consumptions, case 1 ter HP because of its high investment costs combined with quite high energy consumptions.

Case 2 HP and case 2 ter HP become economically similar to case 1 bis in the long term, because the advantage of having lower energy consumptions in a high increase of energy prices scenario counterbalances the high investment cost of the heat pumps.

Case 3 clearly is the best economic case in the long term due to its low energy consumptions.

2.2 Global plant refurbishment scenario

		Final energy consumption (kWhFE/m²/y)		Improvement cost (€/m² including taxes)	Annual operating cost (€/m² including taxes/y)	Percentage gain on operating costs (%)	Return on investment with a 2%/y energy price increase (y)	Return on investment with a 4%/y energy price increase (y)	Annual energy cost - year 1 - (€/m² including taxes/y)	Annual maintenance cost - year 1 - (€/m² including taxes/y)	Maintenance cost percentage on total operating costs - year 1 - (%)
		Gas	Electricity								
Base case (technical)	*Low envelope* *No control* *Old boiler - 1 speed burner* *Plant sized following the low envelope demand* *Split unit for cooling (low efficiency)*	*419*	*36*	*-*	*27*	*-*	*-*	*-*	*26*	*1*	*4%*
Base case (economic)	Low envelope Night time reduction Old boiler - 1 speed burner Plant sized following the low envelope demand Split unit for cooling (low efficiency)	375	33	-	26	-	-	-	25	1	4%
Case 1	Low envelope Night time reduction, **thermostat on radiators** Old boiler - 1 speed burner Plant sized following the low envelope demand Split unit for cooling (low efficiency)	313	31	3	23	13%	1	1	21	1	5%
Case 1 bis (economic)	**Good envelope** Night time reduction Old boiler - 1 speed burner Plant sized following the low envelope demand Split unit for cooling (low efficiency)	139	23	328	12	52%	20	17	11	1	11%
Case 1 ter (economic)	Low envelope Night time reduction **New condensing boiler - modulating burner** Plant sized following the low envelope demand **Split unit for cooling (high efficiency)**	292	33	68	22	15%	14	12	21	1	5%
Case 1 ter HP (economic)	Low envelope Night time reduction Old boiler - 1 speed burner **Heat pump** **Split unit for cooling (high efficiency)**	221	68	108	25	5%	More than 50	44	23	2	7%
Case 2	**Good envelope** Night time reduction, **thermostat on radiators** **New condensing boiler - modulating burner** **Plant sized following the good envelope demand** Split unit for cooling (low efficiency)	70	20	392	8	68%	19	17	7	1	17%
Case 2 HP	**Good envelope** Night time reduction, **thermostat on radiators** **Heat pumps (heating and domestic hot water)** Split unit for cooling (low efficiency)	0	45	450	10	61%	27	19	7	3	26%
Case 2 bis	**Good envelope** Night time reduction **New condensing boiler - modulating burner** **Plant sized following the good envelope demand** Split unit for cooling (low efficiency)	86	21	346	9	67%	17	15	8	1	7%
Case 2 ter	**Good envelope** Night time reduction, **thermostat on radiators** **New condensing boiler - modulating burner** Plant sized following the low envelope demand **Split unit for cooling (high efficiency)**	71	20	399	9	67%	19	17	7	1	17%
Case 2 ter HP	**Good envelope** Night time reduction, **thermostat on radiators** **New condensing boiler - modulating burner** **Heat pump** **Split unit for cooling (high efficiency)**	38	40	464	11	58%	29	20	9	2	21%
Case 3	**Excellent envelope** Night time reduction, **thermostat on radiators** **New condensing boiler - modulating burner** **Plant sized following the excellent envelope demand** **Split unit for cooling (high efficiency)**	26	21	440	6	76%	19	16	5	1	23%

This “global plant refurbishment scenario” table is similar to the “boiler only replacement scenario” table (page 7). The improvement cost of the cases that include the replacement of the old boiler is perceptibly higher, but this has no significant impact on the global trend of the results.

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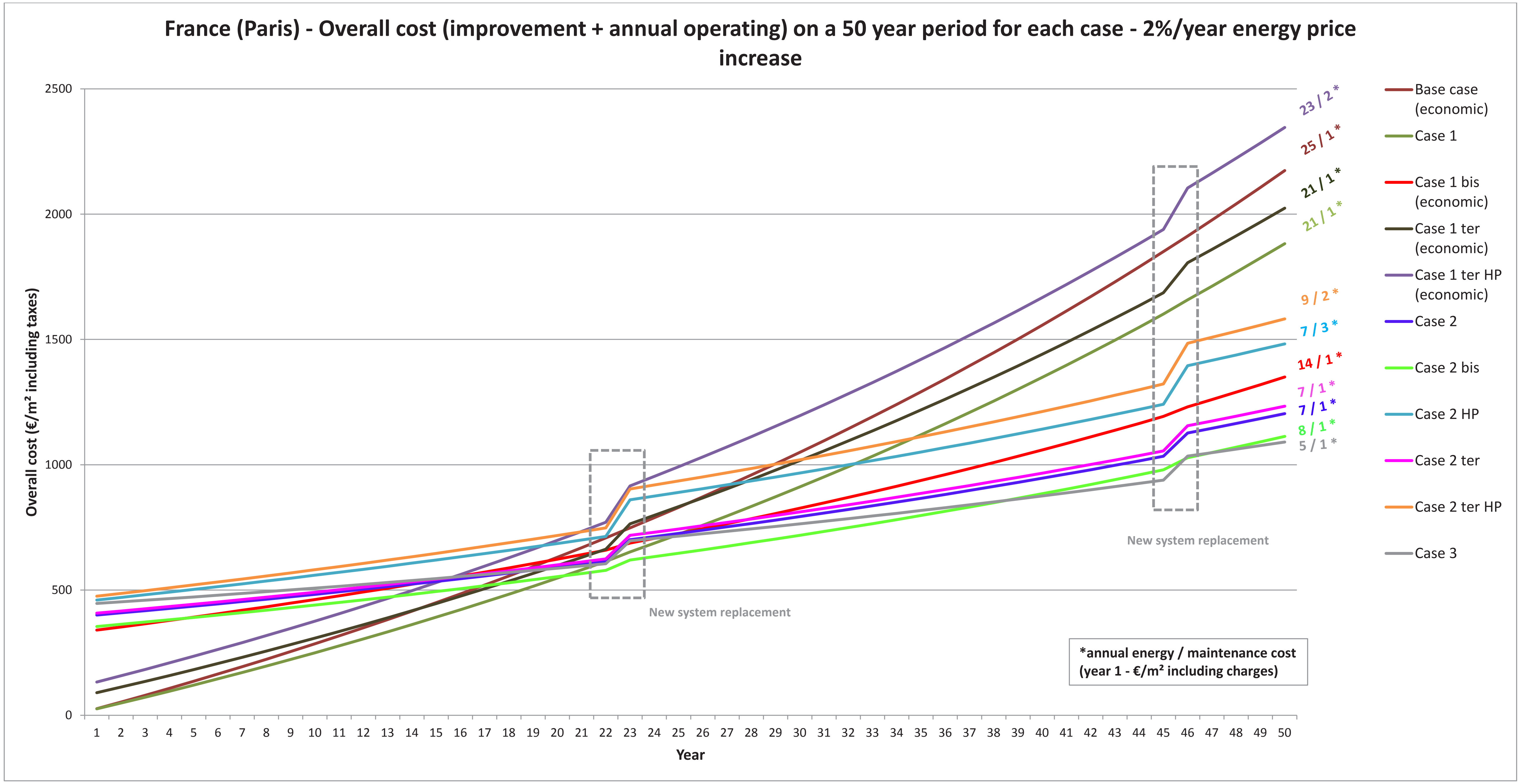
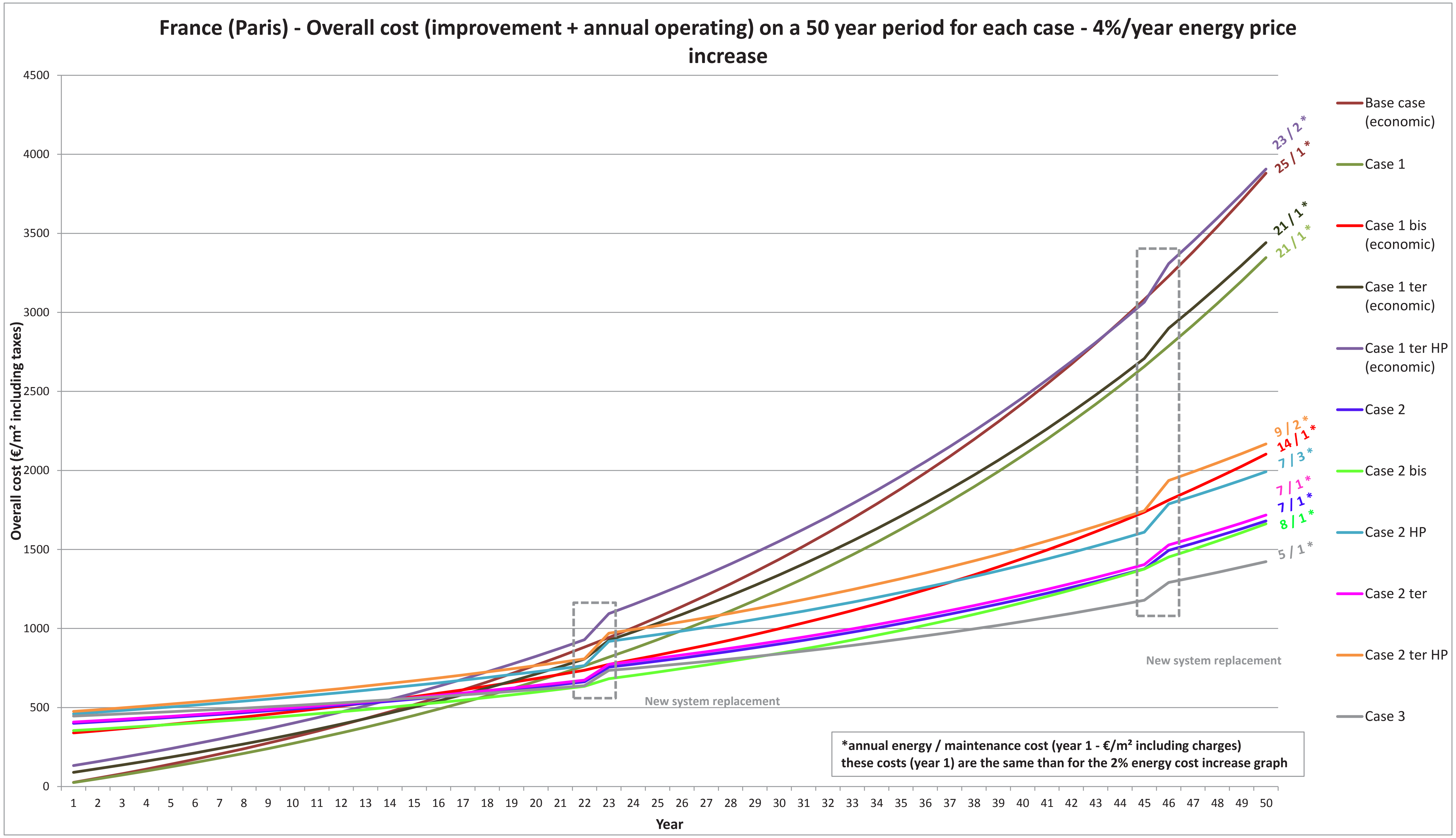


This “global plant refurbishment scenario” graph is similar to the “boiler only replacement scenario” graph (page 8). The plant refurbishment investment cost has no significant impact on the global trend and the overall costs results.

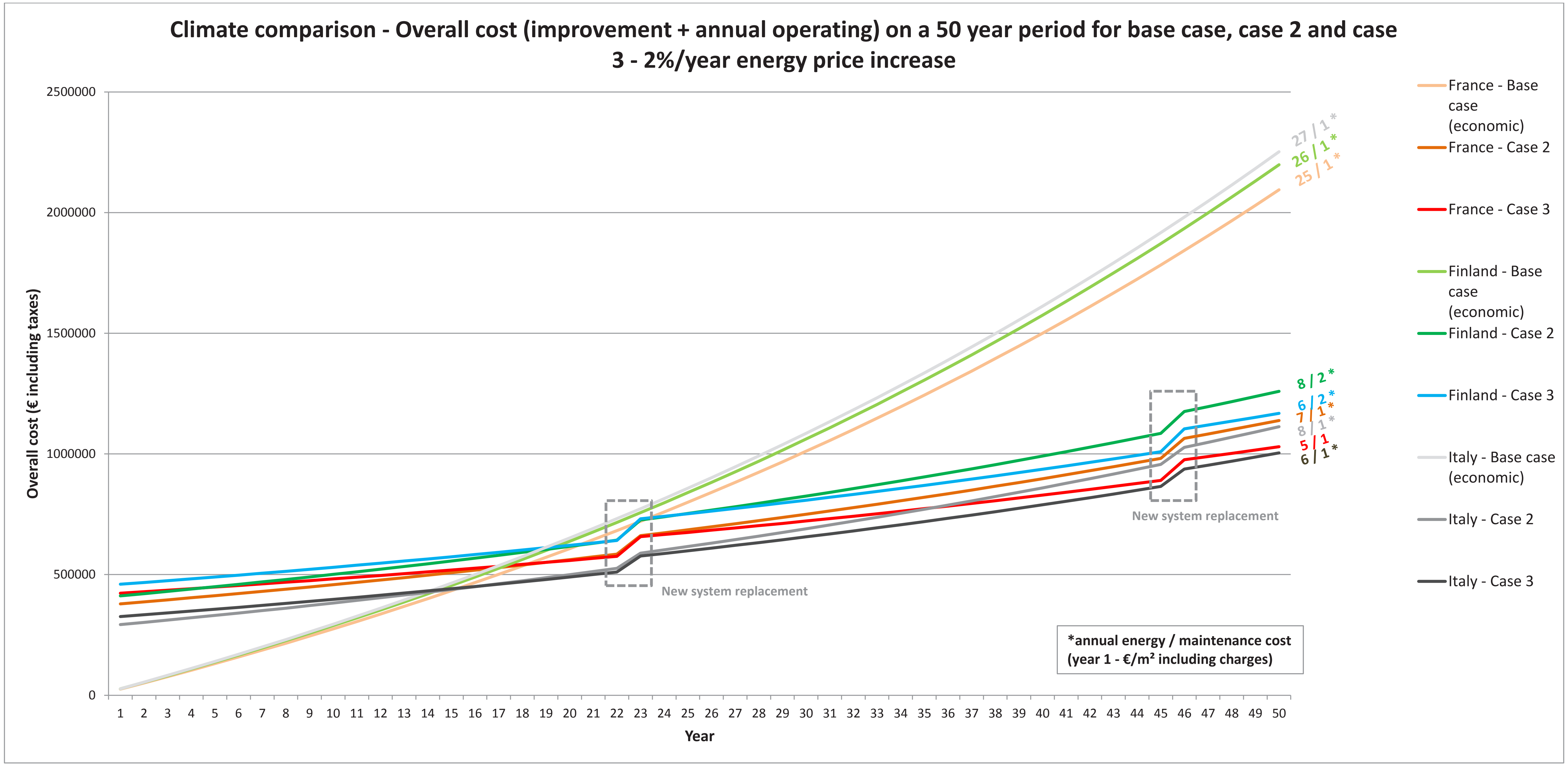


This "global plant refurbishment scenario" graph is similar to the "boiler only replacement scenario" graph (page 9). The plant refurbishment investment cost has no significant impact on the global trend and the overall costs results.

3 Overview: climate comparison

The climate comparison is studied with the "Boiler only" replacement scenario.

3.1 With a 2%/year energy price increase

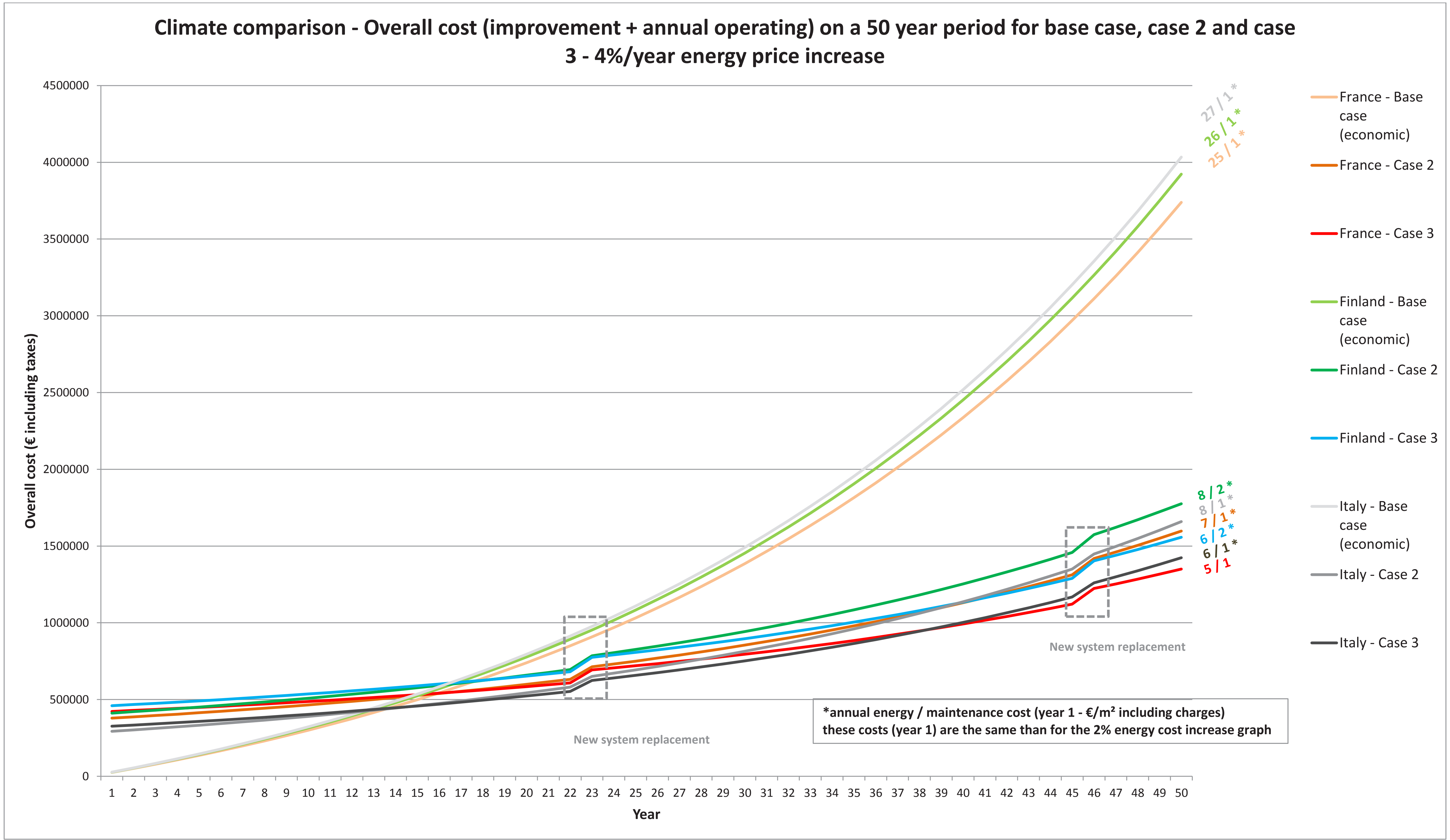


Theses curves show the overall cost for three cases of the three countries considering a **2% energy cost increase per year (low estimation)**.

The trend of the **base case** is close between France, Italy and Finland. The overall cost for Finland is slightly higher than for France. In fact, the lower final energy consumptions in Finland than in France do not completely counterbalance the low energy prices in France. In spite of final energy consumptions similar to Finland's ones, the Italian case curve shows a higher overall cost than both of the other countries because of the high Italian electrical energy costs in particular.

Cases 2 and 3 highlight the differences of investment costs between the studied countries. The low Italian investment cost enables its overall cost to be lower than the other countries, but the gap between France and Italy curves decreases with time due to the lower energy prices in France than in Italy. Finland always has the highest overall cost especially because the investment costs are globally higher in this country than in the other ones.

3.2 With a 4%/year energy price increase



Theses curves show the overall cost for three cases of the three countries considering a **4% energy cost increase per year (high estimation)**.
Compared with the previous "2% energy cost increase" graph, a noticeable difference is the wider gap of the overall cost (which is noticeable especially in the long term) between the most energy efficient cases (2 and 3) and the less energy efficient cases (base).
A high estimation of the energy cost increase also favours the countries with the lowest energy prices. This is why in the long term, France global costs become lower than the global cost of Italy. The Italian electricity cost (0.2428 €/kWh) is much higher than in France (0.1675 €/kWh) and in Finland (0.153 €/kWh). For Italy, 29% of the energy consumptions are electrical for case 2, and 51% for case 3. This can explain why the Italian overall cost for cases 2 and 3 is higher in the long term compared with France than in the previous "2% energy increase" graph.

4 Conclusions: key messages

Increasing energy efficiency by a holistic approach including the envelope is the best economic solution over the lifespan of the building. The improvements only related to thermostats and/or boilers enable to get short returns on investments, but are not very economical in the long term because final energy consumptions, and therefore operating costs, remain high. The improvements concerning the renovation of the envelope give rise to longer returns on investment, but as soon as the return on investment year is reached, they become to a great extent the best economic solution, because final energy consumptions are much lower than with a single heating system replacement.

The only way of reducing significantly the operating and the global costs due to building energy consumptions in the medium term, and even more in the long term (more than 20 to 25 years), is to make an envelope renovation. The gain on operating costs due to insulation is about 50%, while it is lower than 20% for system improvements. Adding performant heating and cooling systems enables to be more economically attractive only if the building also has a good or excellent envelope performance.
Moreover, deep and holistic energy efficiency building improvement works (good/excellent envelope insulation + efficient heating and cooling systems + active technologies) is the best way to reduce energy consumptions and CO_2 emissions, and thus to reach European existing building energy consumption reduction goals (these consumptions are divided per three in case 3 for the building which has been studied, and only consumes 26 kWhFE/m²/y of gas).
The study also shows that improving the envelope before the systems (this is modelled in case 2, while case 2 ter models the opposite) is the least costly way to renovate a building.

This economic study only includes direct costs, and does not take into account the local financial investment aids. These aids, depending on the country and level of revenues, can significantly reduce the investment costs of each of the cases that have been studied. As a result, the energy efficiency improvements can become more economically interesting, with a reduction of the returns of investment times.
Overall costs have been studied with two yearly energy price increase hypotheses: 2% and 4%. If energy prices come to increase more than these hypotheses during one or several years (this eventuality is highly conceivable in the future), the returns on investments of the most energy efficient cases (cases 1 bis, 2, 2 bis, 2 ter, and 3: all containing envelope insulation) would become much lower and more attractive.

The importance of deep renovations including good envelope performances, and leading to very energy efficient buildings goes beyond the direct economic interest. They enable of course very important gains on fossil energy consumptions and consequently on CO_2 emissions, as it is shown in the Transsolar technical study.
They also have a large impact on improving the winter and summer comfort aspects which are studied in the Transsolar piece, but these have not been monetised here.
Furthermore, the ECOFYS study (The role of energy efficient buildings in the EUs future power system) shows that energy efficient buildings with a highly efficient building envelope do not only show benefits at these building technical and economic levels, but that they can also deliver benefits at the electricity system. In fact, these energy efficient buildings have an increased capability to shift electricity demand (especially when the heating system is electrical), and thus reduce considerably the peak demands which are a great problem for the management of the electricity grid and which come at a high cost (not considered in this report). Highly energy efficient buildings are also a pivotal prerequisite to enable the integration of renewable energy sources and a flexible energy supply.
The energy efficiency improvements also engender positive effects on national economies by reducing national debts which are partly caused by the costly importation of fossil energy (which has not been considered within this report).

5 Annex: economic hypothesis and references

5.1 Energy costs

	Energy cost per kWh (€ including taxes/kWh)	
	Gas	Electricity
France	0,0521	0,1675
Finland	0,0641	0,153
Italy	0,0539	0,2428

Source	http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do Eurostat Gas prices for domestic consumers Band I2 : 1000 GJ - 10 000 GJ 2015S2 All taxes and levies included	http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do Eurostat Electricity prices for domestic consumers Band DE : > 15 000 kWh 2015S2 All taxes and levies included

5.2 Maintenance costs

	France	Finland	Italy
	Maintenance costs (€ including taxes)		
Old boiler	220	239	168
Mechanical ventilation	220	239	168
New condensing boiler	330	359	253
Heat pump	770	837	590
Heat pump (domestic hot water)	770	837	590
Split unit for cooling 1 per flat	825	896	632

The costs are based and average costs in France, and have been adapted for the other European countries by using official European statistics:

http://www.youscribe.com/catalogue/rapports-et-theses/actualite-et-debat-de-societe/comparaison-des-niveaux-des-prix-de-la-construction-dans-33-pays-1266301
European Commission Taux de TVA appliquée dans les Etats membres de l'UE Rénovation et réparation de logements privés

The maintenance cost for the new condensing boiler is an average cost which does not take into account whether it is oversized or not.

5.3 Improvement costs

	France		Finland		Italy	
	"Boiler only" scenario	Global plant improvement scenario	"Boiler only" scenario	Global plant improvement scenario	"Boiler only" scenario	Global plant improvement scenario
	Improvement costs (€ including taxes)		Improvement costs (€ including taxes)		Improvement costs (€ including taxes)	
Thermostat on radiators	3135		3407		2401	
Good envelope (internal wall insulation)	271376		294891		207810	
Good envelope (external wall insulation)	315719		343077		241767	
Excellent envelope (external wall insulation)	363458		394951		278323	
New condensing boiler - modulating burner Plant sized following the low envelope demand	17314	24354	18814	26464	13258	18649
New condensing boiler - modulating burner Plant sized following the good envelope demand	10450	17490	11355	19006	8002	13393
New condensing boiler - modulating burner Plant sized following the excellent envelope demand	8866	15906	9634	17284	6789	12180
Heat pump	55880	62920	60722	68372	42791	48182
Heat pump (domestic hot water)	10560	10560	11475	11475	8086	8086
Split unit for cooling (high efficiency) 1 per flat	41250		44824		31588	

The costs are based and average costs in France, and have been adapted for the other European countries by using official European statistics:

http://www.youscribe.com/catalogue/rapports-et-theses/actualite-et-debat-de-societe/comparaison-des-niveaux-des-prix-de-la-construction-dans-33-pays-1266301
European Commission Taux de TVA appliquée dans les Etats membres de l'UE Rénovation et réparation de logements privés