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Heat pump driven by gas engine for heating and domestic hot water generation

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INTRODUCTION

- Low-energy buildings are a key to reduce energy consumptions.

- A low-energy consumption building, as defined in the French RT 2012, is a new building that consumes less than 50 $kWh.m^{-2}.yr^{-1}$ of primary energy (for heating, cooling, domestic hot water, ventilation, and lighting).

- Heat generating systems adapted to the low demand of low-energy buildings are under development.

- The purpose of this study is to design a Heat Pump driven by a gas engine that uses wastewater as the cold source producing domestic hot water and heat for the hydronic system.

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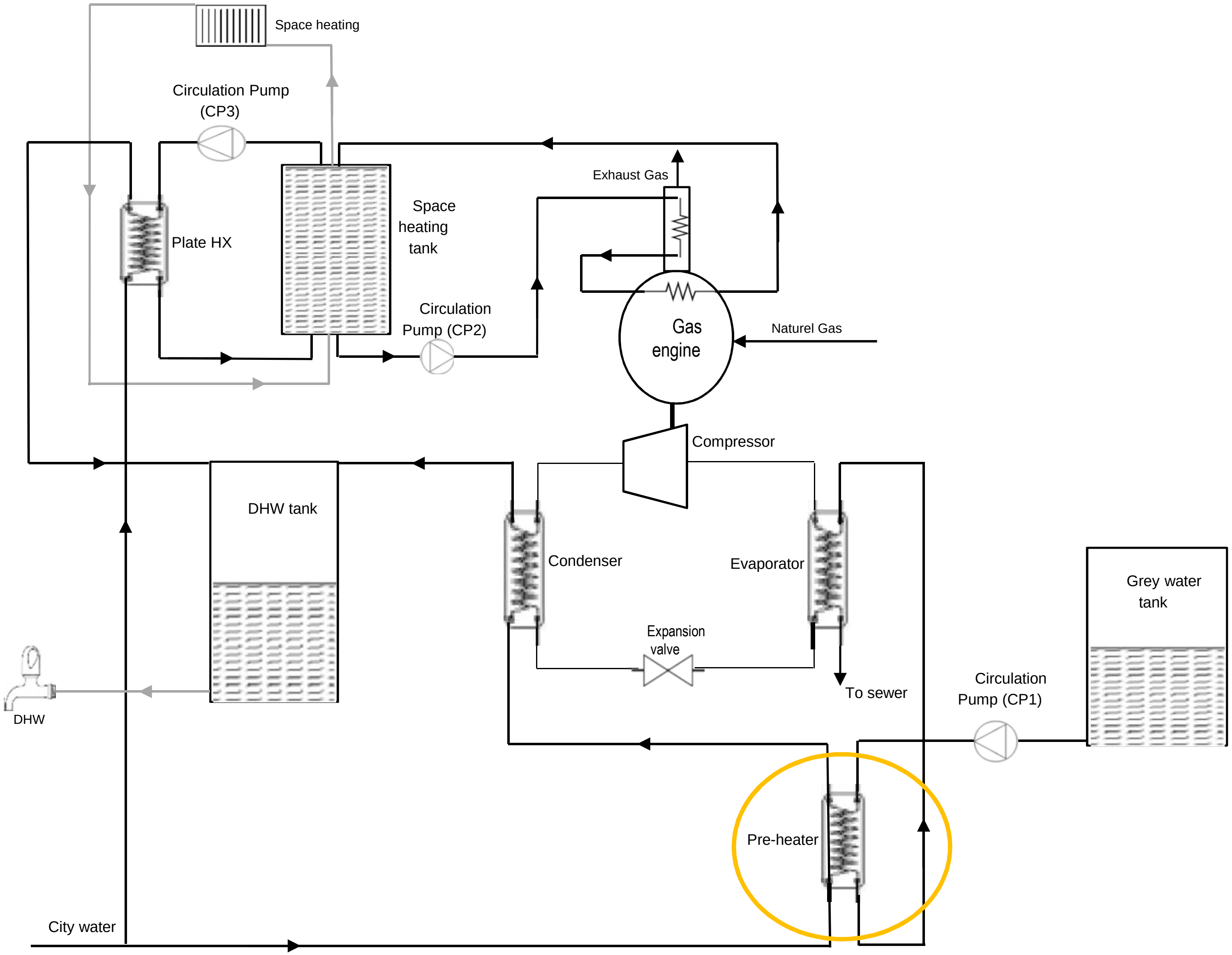
SYSTEM DESCRIPTION



MODEL (1)

➢Heating load and DHW needs:

- Heating demand is calculated using the building simulation software Pleiades+COMFIE
- A building of 4,710 m² is chosen for this study (it is an 8 floors building, composed of 147 double-bedded rooms, a business center, a restaurant and an entrance hall).
- Two reference cities are chosen to analyze the influence of the climate on the need for heating
  - ✓North of France (Trappes)
  - ✓South of France (Nice)
- The DHW withdrawal scenarios come from a domestic hot water guide [AICVF].

MODEL (2)

➢Heating load and DHW needs :

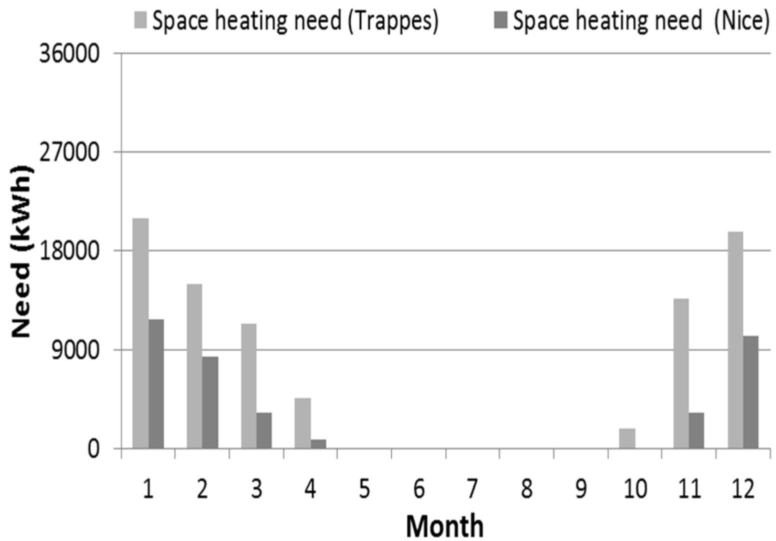


Figure 2: Space heating need

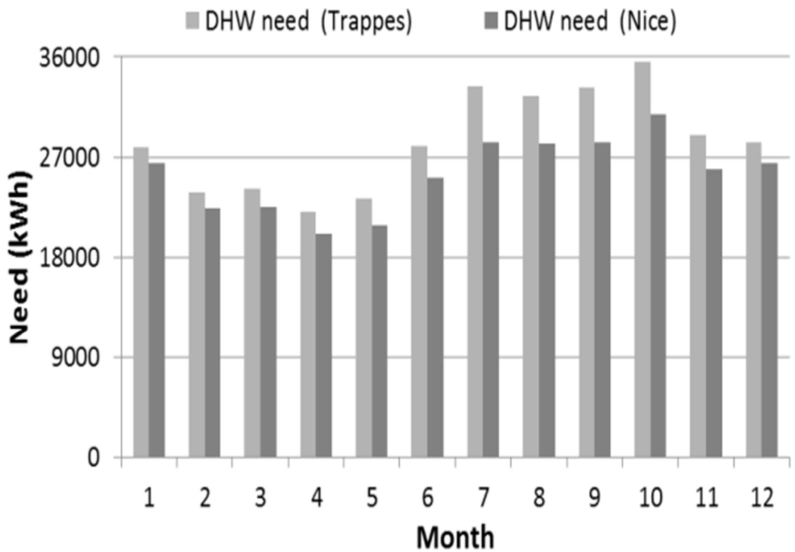


Figure 3: DHW need

- The heating needs in Nice (South) are lower than those of Trappes (North).

MODEL (3)

- Total heating energy

$$P_{condenser} = \dot{m}_{DHW} \cdot C_p \, (T_{DHW} - T_{cw,o}) \quad (1)$$

$$P_{pre-heater} = \dot{m}_{gw} \cdot C_p \, (T_{ww,i} - T_{ww,o}) \quad (2)$$

$$P_{evaporator} = \dot{m}_{gw} \cdot C_p \, (T_{ww,o} - T_{sewer}) \quad (3)$$

$$P_{recovery} = (P_{condenser} - P_{evaporator}) \left(\frac{1 - \eta_{engine}}{\eta_{engine}} \right) \eta_{recovery} \quad (4)$$

$$P_{total} = P_{condenser} + P_{pre-heater} + P_{recovery} \quad (5)$$

- Resources and water flows

$$\dot{m}_{gw} = 0.9 \, \dot{m}_{DHW} \, \frac{(T_{DHW} - T_{cw,i})}{(T_{blend} - T_{cw,i})} \quad (6)$$

$$\dot{m}_{DHW} = \frac{P_{compressor}}{C_p \left[\Delta T_{DHW} - 0.9 \, \frac{T_{DHW} - T_{cw,i}}{T_{blend} - T_{cw,i}} \, \Delta T_{gw} \right]} \quad (7)$$

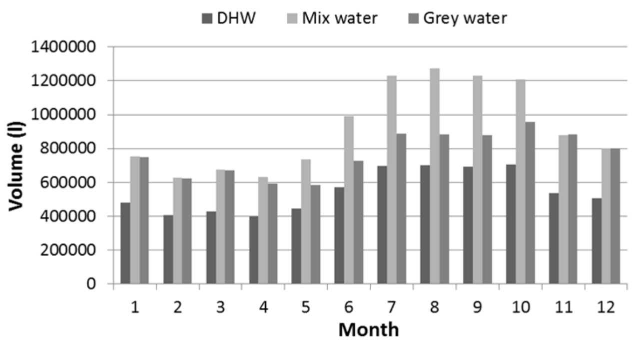


Figure 4: Water flows (Trappes)

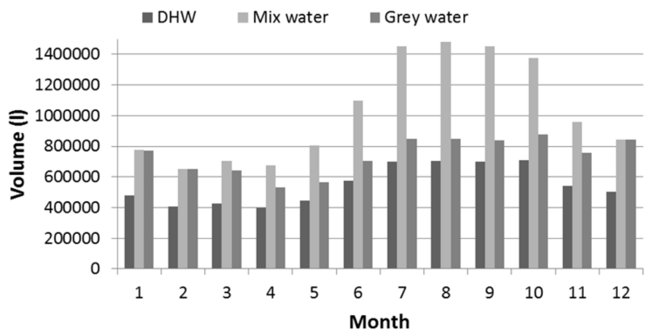


Figure 5: Water flows (Nice)

MODEL (4)

➢Operating time

$$t_{gw-tank} = \frac{\rho \,.\, V_{gw-tank}}{36\,.\,10^5\,.\,\dot{m}_{gw}} \quad (8)$$

$$t_{DHW-SH} = t_{SH-tank} + \frac{\rho\,.\,C_p\left(V_{hw-tank} + V_{withdrawal} - V_{DHW,SH}\right)\left(T_{DHW} - T_{cw,i}\right)}{36\,.\,10^5\,.\left(P_{pre-heater} + P_{condenser} + P_{engine}\left(1-\eta_{engine}\right)\eta_{recovery}\right)} \quad (11)$$

$$t_{DHW} = \frac{\rho\,.\,C_p\left(\left(V_{hw-tank} + V_{withdrawal}\right)\left(T_{DHW} - T_{cw,i}\right)\right)}{36\,.\,10^5\,.\left(P_{pre-heater} + P_{condenser}\right)} \quad (12)$$

- The operating time is equal to the lowest value between $t_{gw\text{-}tank}$, $t_{DHW\text{-}SH}$, t_{DHW} and 1

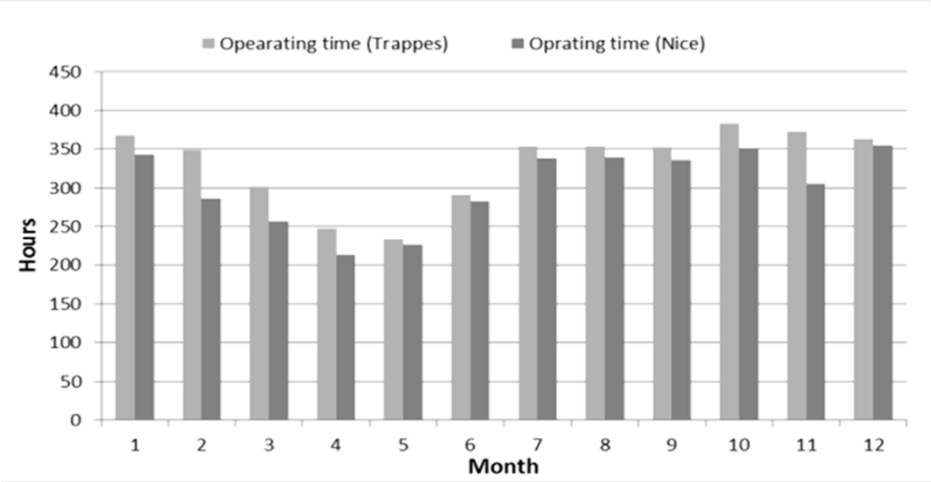


Figure 6: Monthly operating time

- The operating time during the warm season is lower than that of cold season.

MODEL (5)

➢Production and consumption

Nature of the flow	Value	Condition
DHW produced (l)	$V_{DHW} = \frac{36.10^5 \left(P_{HP}.t_{SH-tank} + P_{GHP}.(t_{op} - t_{SH-tank})\right)}{\rho.Cp\,(T_{DHW} - T_{cw,i})}$	$t_{SH-tank} < t_{op}$
	$V_{DHW} = \frac{36.10^5 .P_{HP}.t_{op}}{\rho.Cp\,(T_{DHW} - T_{cw,i})}$	else
Grey water consumption (l)	$V_{gw-tank} = \frac{36.10^5 .\dot{m}_{gw}.t_{op}}{\rho}$	
Space heating storage temperature (°C)	$\Delta T_{SH-tank} = \frac{36.10^5 .P_{engine}\left(1-\eta_{engine}\right) t_{SH-tank}}{\rho.Cp.V_{SH-tank}}$	$t_{SH-tank} < t_{op}$
	$\Delta T_{SH-tank} = \frac{36.10^5 .P_{engine}\left(1-\eta_{engine}\right) t_{op}}{\rho.Cp.V_{SH-tank}}$	else
Heat pump gas consumption (kWh)	$E_{engine} = P_{engine}.t_{op}$	

- This table summarizes what the heat pump produces or consumes depending on time.

MODEL (6)

➢Sizing of storage tanks

- DHW tank
$$V_{DHW-tank} = {}^{1}/_{3}\,\frac{36\,.10^5\left(\sum_{i=1}^{24} E_{DHW,i}\right)_{max}}{\rho\,.Cp\,(T_{DHW}-T_{cw})} \qquad (13)$$
- Space heating tank
$$V_{SH-tank} = 0.3\,\frac{36\,.10^5\left(\sum_{i=1}^{24} E_{DHW,i}\right)_{max}}{\rho\,.Cp\,(T_{CL,o}-T_{CL,i})} \qquad (14)$$
- Grey water tank
$$V_{gw-tank} = 0.9\,V_{DHW-tank}\,\frac{(T_{DHW}-T_{cw})}{(T_{mix}-T_{cw})} \qquad (15)$$

➢Operating conditions

$$V_{DHW-tank,limit} = \frac{36\,.10^5\left((E_{DHW})_{max}-E_{HP}\right)(1+0.05)}{\rho\,.Cp\,(T_{DHW}-T_{cw})} \qquad (16)$$

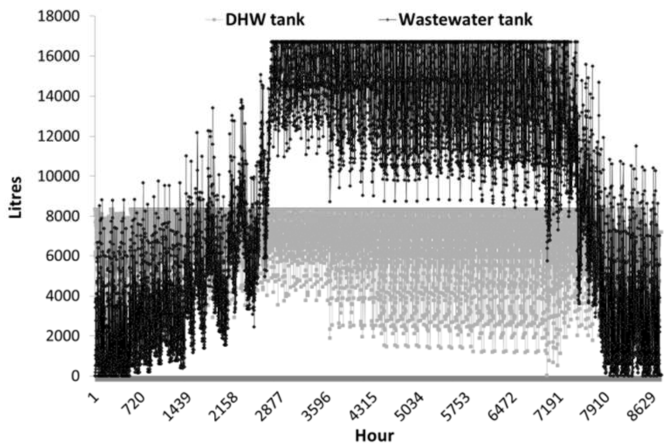


Figure 7: DHW and wastewater tanks (Trappes)

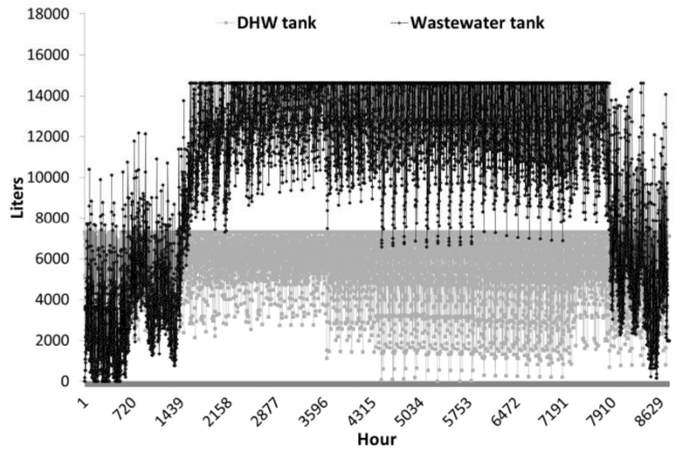


Figure 8: DHW and wastewater tanks (Nice)

- Figures allow us to recognize hot season. During this period, GHP does not need to use all available grey water.

RESULTAS (1)

- The seasonal Gas Utility Efficiency (GUE) of the system is calculated based on simulations; they predict a seasonal GUE higher than **2.2** (220 %) in both cities.

	Hotel	
	Trappes	**Nice**
Gas engine consumption (kWh)	170,449	155,978
Renewable Energy production (%)	56 %	54 %
Space heating covered by the GHP (%)	59 %	85 %
Gas utility efficiency (GUE)	**2.3**	**2.2**

- Space heating production is limited by the recovery of the engine.
- The high demand in the cold seasons is not fully insured by GHP.

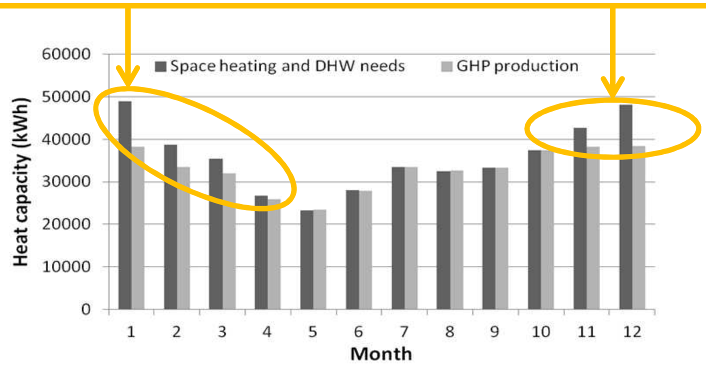


Figure 9: Heats capacity (Trappes)

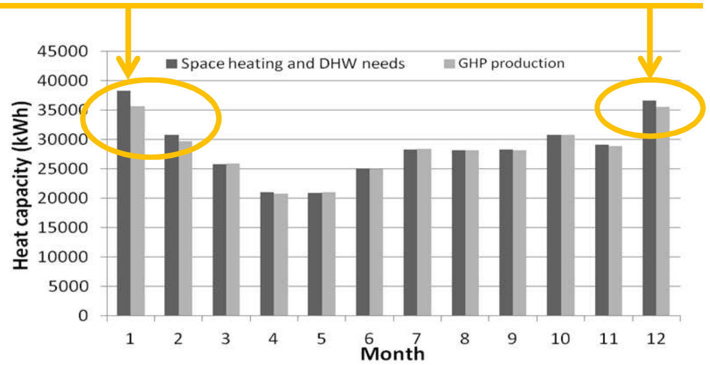


Figure 10: Heats capacity (Nice)

RESULTAS (2)

➢The overall GUE of the system decreases slightly in hot season due to the low heating load and the high city water temperature

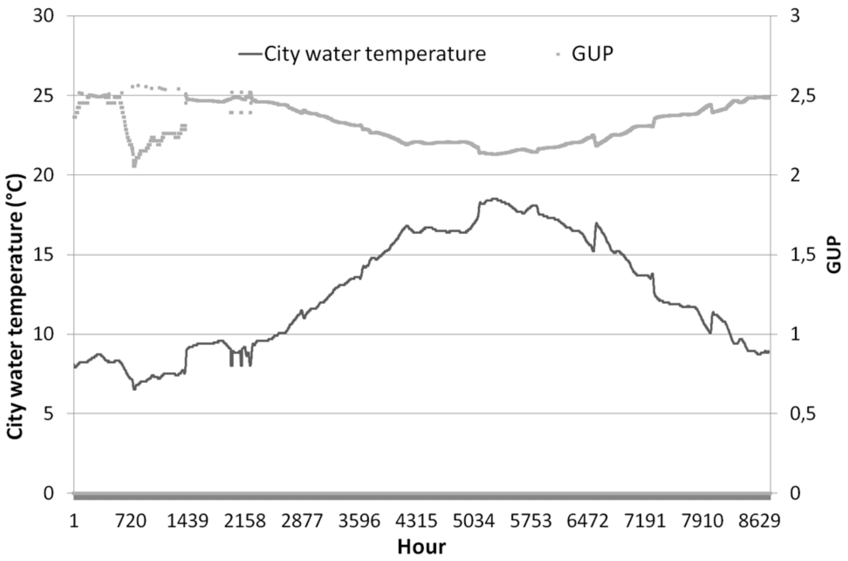


Figure 11: Evolution of the GUE of the GHP and the city water temperature (Trappes)

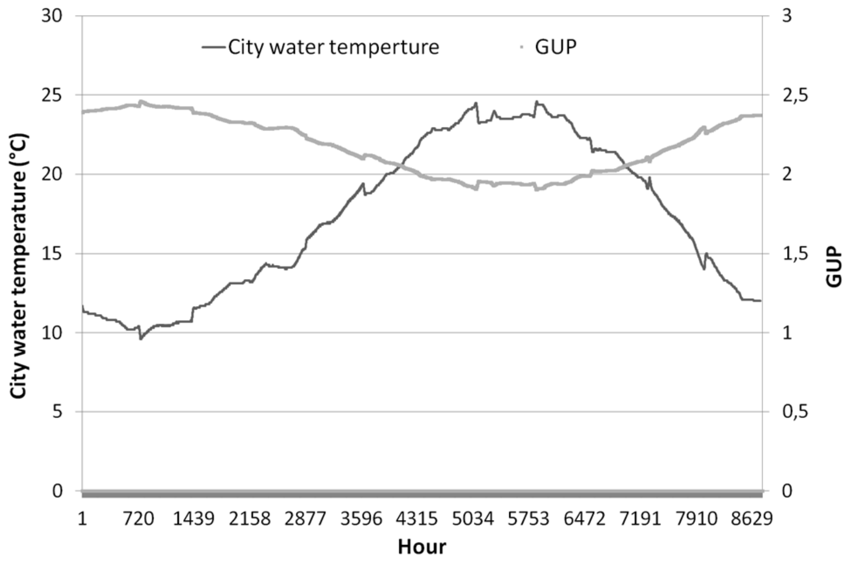


Figure 12: Evolution of the GUE of the GHP and the city water temperature (Nice)

CONCLUSIONS

- A new design of a Heat Pump driven by a gas engine is presented.
- The direct heat exchange (recovery) and the thermodynamic lever allow grey water GHP to achieve high performances.
- The heat released by the engine, is either valorized in space heating network or in DHW and reduces its operating time.
- the pre-heater keeps almost constant operating conditions of the evaporator and the condenser
- the overall efficiency of the system does not vary much within months
- The reduction of space heat needs will allow the GHP to cover it over the year (this reduction has been fixed by the French regulation RT 2020).