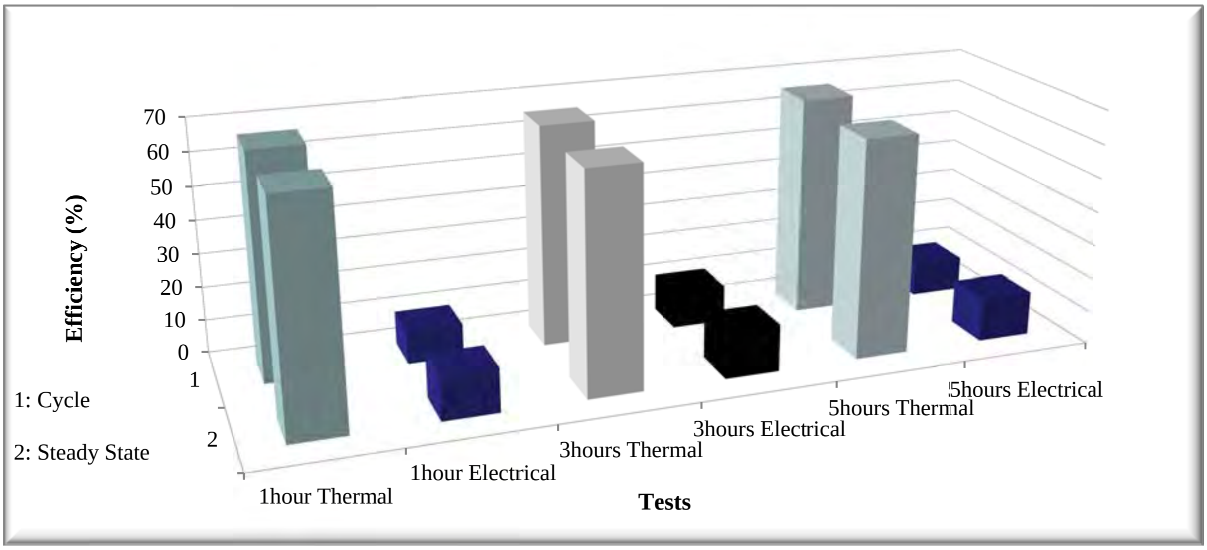

Fig. 3. Steady state and cycle efficiency measurements for different test durations.

It can be observed in *fig. 3* that the thermal efficiency is about 66% for all tests during the steady state operation and for the whole cycle monitoring. The electrical efficiency was found to be about 10% for the whole cycle measurements and 12% for the steady state measurements. These values were consistent for all tests. The thermal efficiency of the mCHP has been found to be considerably lower than that of a condensing boiler. This finding is consistent with [11]. In cycle and steady state measurements, the thermal efficiency remained at approximately the same level. This is due to the water circulator pumping water throughout the system after the combustion process has ended to allow more effective cooling of the engine (*fig. 5*). The cycle electrical efficiency is affected by the dynamic performance during start-up (*fig. 4*) and is lower than the steady state efficiency. It is believed that this low performance is caused by the lower gas pressure of the working gas inside the Stirling engine. This was a design trade-off to avoid wear of moving parts.

The start-up and rundown characteristics of the Whispergen Mk Vb mCHP are presented in *fig. 4* and *5*, respectively.

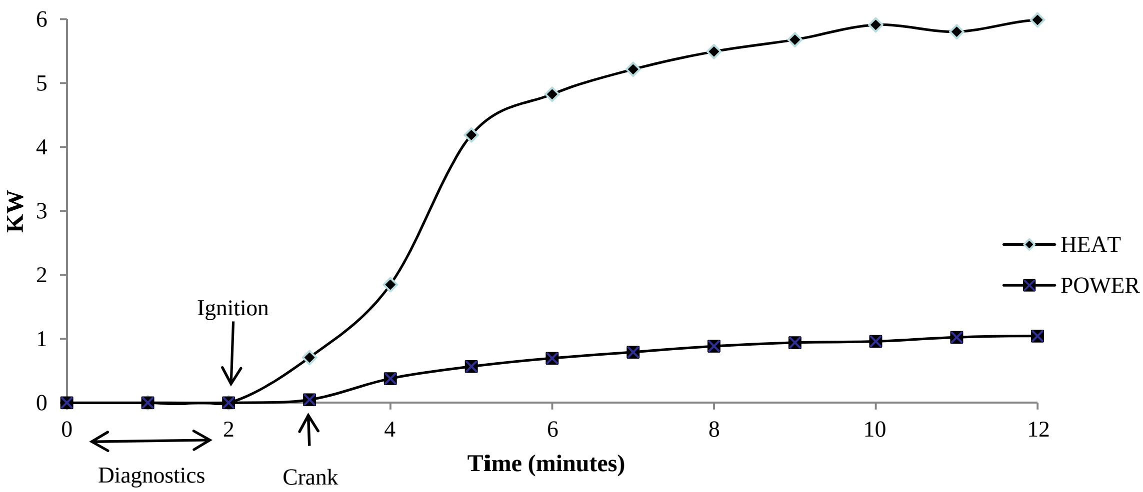

Fig.4. Breakdown of Whispergen Mk Vb start-up characteristic.

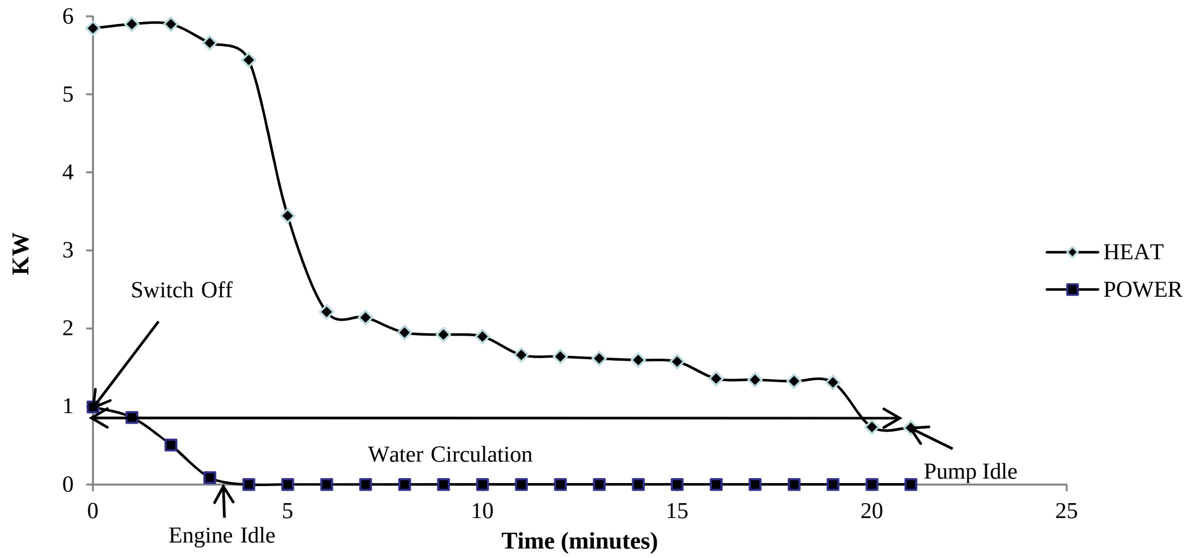

Fig. 5 Breakdown of Whispergen Mk Vb run-down characteristic.

The results presented above were used as input data for RETScreen software and a comparison between the mCHP system and a conventional energy scenario including a condensing boiler and grid electricity was carried out. The results are presented in *table 2* for two houses with different heat demands.

Table 2. Annual performance of mCHP compared to a conventional system for 2 houses.

House Type	5 kWth semi -detached	9.5 kWth detached
Annual Benefits	£-54	£87
Annual carbon savings	-500 Kg	300 Kg

Results obtained using RETScreen indicated that the particular mCHP system would be unfeasible for a relatively new semi-detached house with a low heat demand. The feasibility of the system was considerably improved for a larger house with a higher heat demand. Similar results can be found in literature [12]; however, different methods and models were used. It is believed that the particular software neglects the transient performance of both the mCHP unit and the heating boiler, as well as the dynamics of domestic energy demand and energy pricing. Furthermore, the estimated electricity demand does not include the electricity consumption of the heating boiler which may add up to the electrical about 10% of the boiler rated output [11]. Additionally, the software sizes the conventional heating boiler based on solely heat demand (5 kW_{th}). In reality, this demand would be met by a 15 kW_{th} boiler. This over sizing limits the efficiency of the boiler. The software prediction is more encouraging for the detached type house as the mCHP displaces more grid electricity by operating for longer periods to meet the higher heat demand. The economic savings are attributed to the recently introduced feed-in tariff (10 pence per every kWh of electricity) [13] and the carbon savings are associated to the carbon intensity of the displaced grid electricity.

The mCHP was tested using the programmer controller to set conditions for typical days during the annual period. The transient characteristics of its performance including the hot water consumption and reheating were included in all calculations and the yearly performance was modeled. The heat generated from the mCHP is plotted in *fig. 6*. The temperature line illustrates the increase of the heat load when the hot water consumption occurs. This additional heat load is met by the auxiliary burner. It can be seen from *fig. 6* that the total heat generation for approximately two hour period is equal to 11.5 kW_{th}.

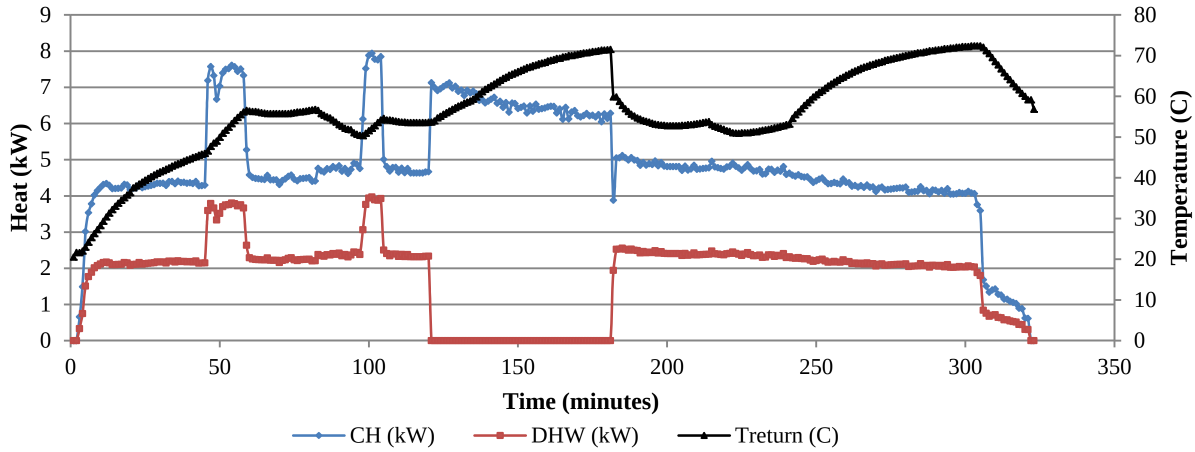

Fig. 6. Heat generation during the evening of a winter weekday

The annual performance of the mCHP compared to the dynamic simulation results of the conventional heating system is presented in *table 3*. The price of the mCHP unit and condensing boiler installed is about £3500 and £750, respectively. The simple payback period is calculated taking into account the difference in the capital cost, fuel consumption and the feed-in tariff.

Table 3. Annual performance of MCHP compared to a dynamically modeled conventional system.

Heating Plant	mCHP
Annual monetary savings	16%
Annual carbon savings	0.17%
Simple Payback Period	8 years

4. Conclusions

The feasibility study demonstrates that the mCHP compared to a condensing boiler in conventional domestic energy scenario can provide annual monetary benefits of up to 16% (taking into account new feed-in tariff, difference in the fuel consumption and assuming the same level of maintenance costs).

The performance of the mCHP is enhanced by a hot water consumption. This additional heat load caused the cooling water temperature to drop at around 50 ^{o}C where condensation is believed to take effect. This improved the mCHP thermal efficiency from 66% to 73%. This improvement however was associated with marginal carbon savings (0.17%) compared to a conventional energy scenario. This is believed to be caused by the low electrical and thermal efficiencies of the particular unit along with the electricity generated during the pre-heating period which is not consumed and therefore does not displace any grid electricity. To support this conclusion, research on the previous Whispergen Mk III mCHP unit [9] with 10% higher overall efficiency indicated higher carbon saving potential. The difference between the current results and those obtained by RETScreen is believed to be due the the deficiencies in electricity demand modeling, energy pricing variations and the thermal efficiency of the mCHP varying with the heat demand.

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