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Low carbon solution for heating and cooling in Multi Family Buildings

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Abstract

European legislation is driving the energy efficiency of modern buildings. Heat pumps are representing a good solution to achieve this goal, but they are not commonly used in Large Multi Family buildings. Conventional solutions for heating these buildings usually rely on high temperature heat generators or District heating loops to supply heat centrally into a distribution network within the building. There are a number of issues with these high temperature distribution loops. The overall efficiency of this system is not very high due to the high losses of the heat network especially in summer. The high losses cause significant overheating in communal areas and corridors of these types of buildings and separate ventilation measures often have to be provided. Standard heat pumps cannot easily be integrated to such system due to the high flow temperature as the required high temperatures affect high efficiencies.

This paper discusses the integration of heat pumps in Multi Family Buildings via a low flow temperature energy network. It demonstrates how the application of heat pumps for the generation of the heat instead of the current solution has many benefits. A design study on an actual Multi Family building in London highlights the main advantages of such system.

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1. Background

In Europe, the Energy Performance of Buildings Directive (EPBD) is driving the energy efficiency of buildings. In the UK, the long term heating strategy is to increase the share of district heating dramatically. Latest estimates suggest that 14% of all heat could be provided via district heating by 2030 with and increase to 43% by 2050 [1]. Heat pumps represent a good solution for single dwellings to achieve high efficiency and reduce CO₂ emissions, but the application of heat pump technology in Multi Family Buildings is problematic. The most common solution today to heat these buildings is a small heat network within the apartment buildings. The heat is generated by a combination of gas boilers and CHP units or connected to a wider area heat network. The heat network within the building has a flow temperature between 60°C and 80°C. Heat networks in the UK were estimated to provide 2% of heat demand in 2009 which is very low compared to the 10% market share found in Europe and the levels found in Scandinavia (Denmark 70, Sweden 50%) [2].

London has a more ambitious plan, the London Plan Energy Strategy [2] which offers new challenges and opportunities for low temperature district heating and the use of heat pumps.

The overall aim of the London plan is to achieve a sustainable development of the city. From an energy point of view, it supports greater use of renewable and low carbon generation technologies. The target is for London to achieve a 60% reduction in London's CO₂ by 2025 (against 1990 levels) and to generate 25% of its heat and power requirements through the use of local, decentralised energy systems by 2025.

2. Typical centralized heating system

A fully centralized heating system is usually the preferred option for developers in cities. This centralized system consists of a main plant room with several heat generators, powering a high temperature water loop under the “control” of a Building Management system. This heating loop feeds individual heat interface units in each dwelling to provide heating and hot water on demand. The heat interface unit is made of a plate heat exchanger with various valves and pumps to either distribute the heat to the heating system in each dwelling or to heat the hot water as and when required. For a typical London multi-occupancy building, the heat interface unit is fed with water at 70°C and the return temperature is around 40°C.

The designer of such system make educated assumptions in term of users diversity to size up the components of heat generators in the plant room to cover and can ensure that the mix of generator meets the energy efficiency requirements imposed by legislation. This kind of design approach tends to lead to over-size plant room as described in more details later on in this paper.

The main issues common to centralised heating are:

- Low system efficiency, as a results of distribution loop heat losses
- Over-heating of shared areas
- Plant room over-sizing (physical size and output capacity)
- Thermal stress on district heating pipe from temperature fluctuations

Case studies, such as Seager distillery, have shown that the actual efficiency was far worse than anticipated at the design stage. Annual efficiencies as low as 26% were quoted for a re-development located in London [3]. This efficiency was averaged between a typical winter efficiency of 32% and a low summer efficiency of 19%. This low efficiency in the summer months is explained by the need to have an operational high temperature network 24 hours a day, 7 days a week to satisfy the hot water demand in individual dwellings.

These efficiencies contrast with the standard values found in the UK Standard Assessment Procedure (SAP, standard methodology used to assess the energy performance of UK buildings) mainly because SAP is underestimating the thermal losses of residential communal heating systems by assuming a default district heating loss factor of only 5% for most new build housing schemes. This is currently under review to reflect heat losses more accurately.

For this particular study, a typical development of low energy apartments, was modelled in order to carry out various simulations on heat losses, overheating and system efficiencies. The basis of the model was a combination of several London based developments and add the following features:

- 55 apartments in one apartment block (880m distribution network).
- U-values in line with UK current building regulations
- Each apartment equipped with Mechanical Ventilation with Heat Recovery
- Total peak load of 137kW for heating and 66kW for hot water.
- Annual DHW load of 2100kW.h.
- Three heating load scenarios were considered, 5000kW.h (High), 2500 kW.h (Medium) & 1500kW.h (Low)

2.1. Network heat losses

The main reason for such low efficiency as seen in the case studies is the distribution heat loss through the heat network. High distribution losses are often contributed to poor workmanship at the point of installation of the distribution system and poor insulation levels of the pipes. In order to better understand what portion of the losses are contributed by installation issues and what portion is caused by system design a model was developed to calculate the pipework losses based on insulation levels and water flow temperatures. The outcome of the model shows the best case scenario in terms of network losses and distribution system efficiencies because it doesn't take any installation issues into account.

The influence of the network temperature can clearly be seen in Fig. 1. The network efficiency is directly related to the network losses and high pipe losses explain the low efficiency seen on various sites.

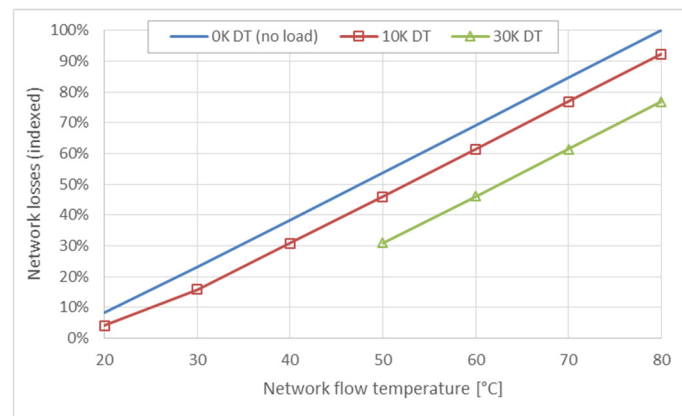


Fig. 1. Comparison of network losses for varying flow temperatures and temperature differences (Indexed to 80°C flow temperature)

As expected, the heat losses are highest at high temperature and Figure 1 illustrate the benefits of very low temperature networks.

For this case study, the total length of distribution network was 880m. Two pipe insulation options were considered when looking at heat losses. Pipe thickness for the standard design and improved design are shown in table 1 below.

Figure 2 shows the network heat losses expressed as a percentage of the total heat generated for 4 typical cases: at peak load (heating and hot water demand) with 2 types of insulation and a hot water only case with the same 2 types of insulation. The peak load is the best case in terms of network losses. On the opposite end of the spectrum, a day with low or no heating demand but with hot water requirement is when the network losses are maximal as described previously.

Figure 3 shows annual network losses in the case of standard insulation. These losses have been estimated based on a time averaged of heating, hot water generation and no heat demand over a year. The results at high loop temperature are in line with a study of Heat networks conducted by the UK Department of Energy & Climate Change [5].

Figure 4 shows the resulting network efficiency defined as the annual “Delivered heat” over “Total heat generated” in the plant room. This highlights the benefits of going for low or very low temperature loops.

Table 1. Pipe insulation used in case study

Pipe size	Standard insulation thickness [mm]	Improved insulation thickness [mm]
DN125	30	40
DN100	30	40
DN80	25	35
DN65	25	35
DN50	25	30
DN40	20	30
DN32	20	25
DN25	20	25

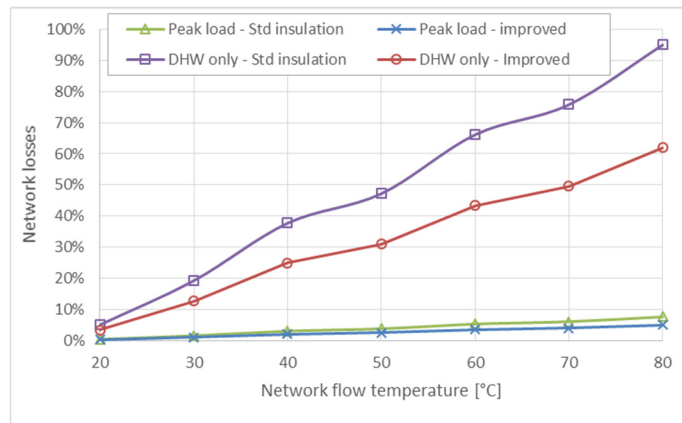


Fig. 2. Influence of pipe insulation on network losses

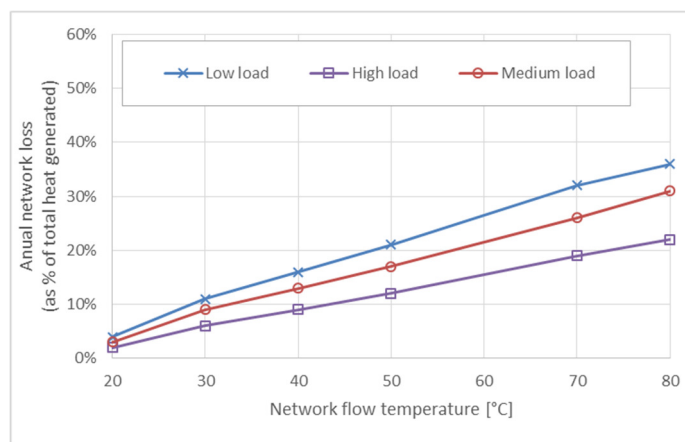


Fig.3. Annual distribution losses as % of total heat generated for various heating loads

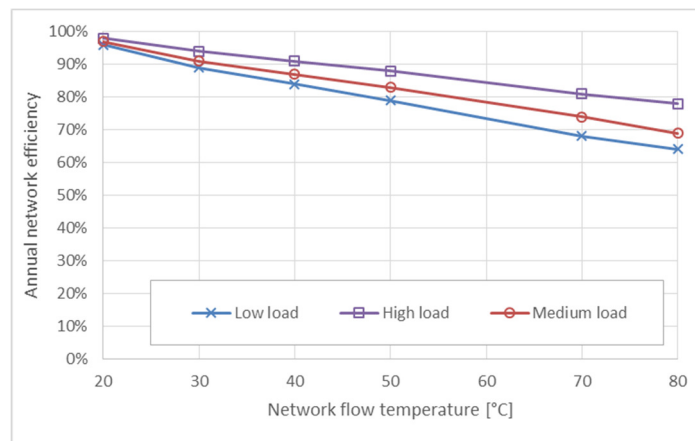


Fig. 4. Annual Network efficiency for various heating loads

2.2. Over-heating

Over-heating has been highlighted as a real problem in corridors of apartment blocks for new and refurbished properties [6]. It is particularly frequent during summer in the shared areas of an apartment block (corridors, stairs shafts...) but can also occur when heat demand is low. At this time, there is no need for heating but there is a constant need for hot water. This requires a constant feed of high temperature water through the heat network in order to service the hot water and leads to substantial over-heating.

A Computational Fluid Dynamic simulation was carried out to assess the heat losses in winter & summer with a typical 70/40°C loop. General assumption used for the models are shown below:

- Only the buoyant air volume in the corridor has been modelled.
- Heat loss of 0.16 W/m²/K 21deg C have been applied to the walls of the corridor.
- Initial starting temperature of 21°C has been applied in all scenarios.
- Mesh size 2.6M elements in all scenarios.
- Stairwell inlet has a pressure of 0Pa and a temperature of 0°C for winter and 28°C for summer.
- No ventilation has been assumed as a ventilation rate of 0.01m³/s
- Standard ventilation means a ventilation rate of 0.1m³/s
- Purge ventilation = means a ventilation rate of 0.33m³/s
- Heat loss from the pipes was assumed to be total of 700W. (10.93W/m x 32 m x two pipes)

Figure 5 shows the temperature distribution in a corridor in one floor of an apartment block. The corridor temperatures on a summer day (28°C ambient) can reach up to 35°C, even when a purge ventilation has been put in place to keep the place bearable. Corridor temperatures in excess of 20°C are also found on a cold winter day (0°C ambient). In this instance, the issue is not a comfort issue but an energy issue. All this heat being lost to the corridor contributes to the excessive losses found in the various case studies mentioned above. If the apartments are energy efficient with high level of insulation, as is the case in this case study, then the warm corridor do not necessarily contribute to heat gain into the dwelling.

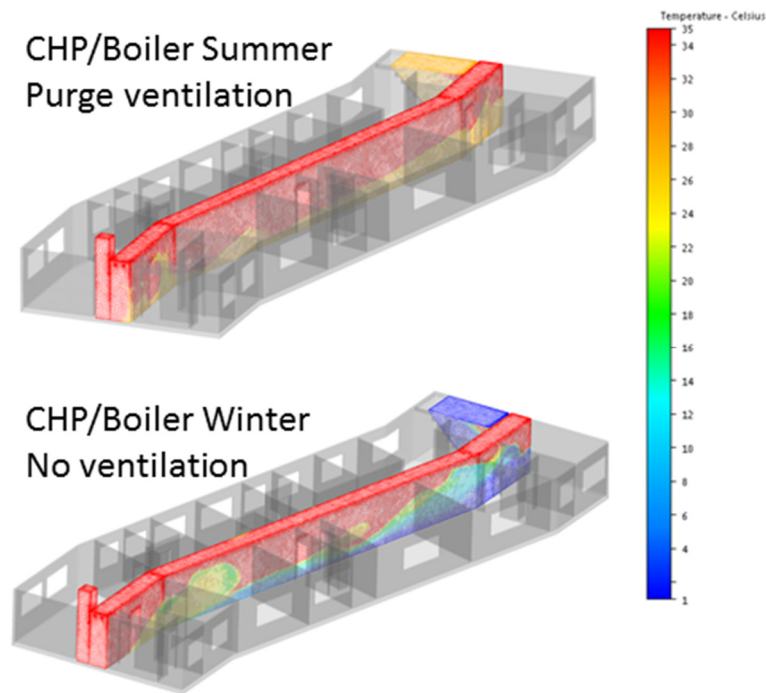


Fig. 5. Temperature profile in a corridor with 70°C water loop

3. Heat pumps as a solution

Heat pumps are potentially an important element in multi-occupancy dwellings. They offer many advantages in such applications but also have their limitations in conventional district heating network. Heat pumps have lower output temperature than the expected 70-80°C temperature in the network. When looking at heating only, this should not be an issue and the flow loop temperatures could be reduced to more favourable temperatures for heat pumps if the heat emitters have been sized up properly for a low temperature applications.

The use of heat pump could be applied in several different ways:

- heat pump as a heat generator for the centralized heating loop with under-floor heating or fan coil convectors for heating.
- individual heat pump in each home working from a very low temperature loop
- a combination of the above

The approach of using a heat pump or other renewables heat generators as a replacement to a gas or oil boiler is often considered as a way of reducing the CO₂ emissions of the system. Because district heating or centralized heating infra-structures are not fuel specific, the source can be adjusted to meet legislation or emissions targets.

A heat pump can also be used as a secondary heating device for heating and hot water in each apartment. This solution is particularly elegant for working with very low temperature heat network. It can be used to raise the

temperature from a very low temperature network (at say 20°C) to a useable temperature inside the home. This combines all the advantages of a low temperature loop described in previous sections with the efficiency of a heat pump.

A very low temperature at 20°C can easily integrate with waste heat unlike the current heat networks which require high temperatures. This can work well with low grade energy available widely in cities, even using waste heat from sewers as a potential, as described by a report on the use of waste heat [2]. Figure 6 illustrate option for integrating heat pumps in parallel with other solutions or as a stand-alone solution. This concept can even be pushed further by having a one loop system where a low temperature loop is shared between different appliances to contribute to both heating and cooling. The particular advantage in this case is that the heating and cooling demand negate each other and the demand on the central heating or cooling equipment is reduced.

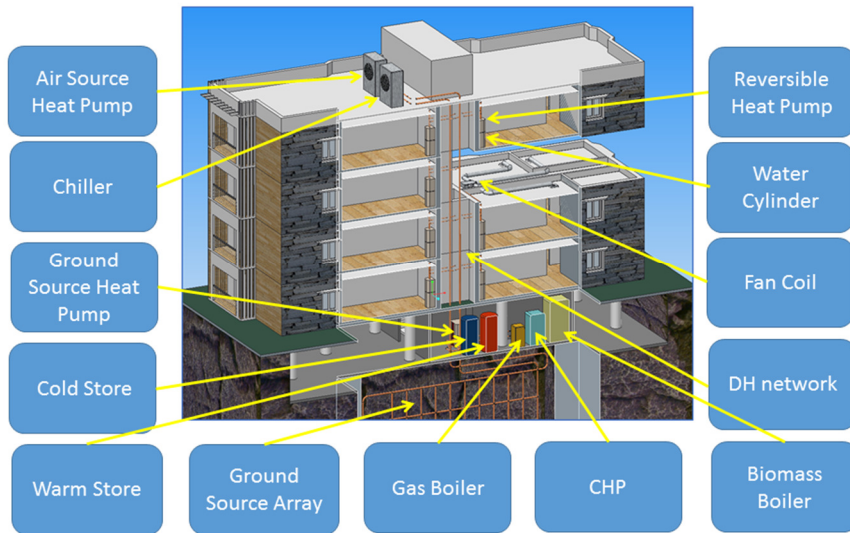


Fig. 6. Illustration of where heat pumps would fit in such solution

The proposed heat pump solution for each apartment consists of a compact, low capacity water source heat pump combined with a hot water cylinder. The low temperature loop is the heat source and the heat is distributed to the dwelling via under-floor heating, fan coil convectors or low temperature radiators. Preference is for a low temperature heat emitters to maximize system efficiency. Frost protection functions are built into the water heat pump to ensure that the source loop stays well above water freezing point in the event of the source pump failing / flow rate being reduced unexpectedly.

For dwelling requiring summer cooling, the heat pump is reversible and allows to divert the rejected heat from the cooling process to the hot water cylinder. If the cylinder is at temperature then the heat can be rejected into the “source” loop. For a mix of heating and cooling requirements, this option is ideal because dwellings on opposite aspects of a building can have different requirement and the net energy balance between cooling and

heating of the source can be nil / null. This could happen where the South side of the building could be requiring cooling while the North side needs heating (Figure 7.b).

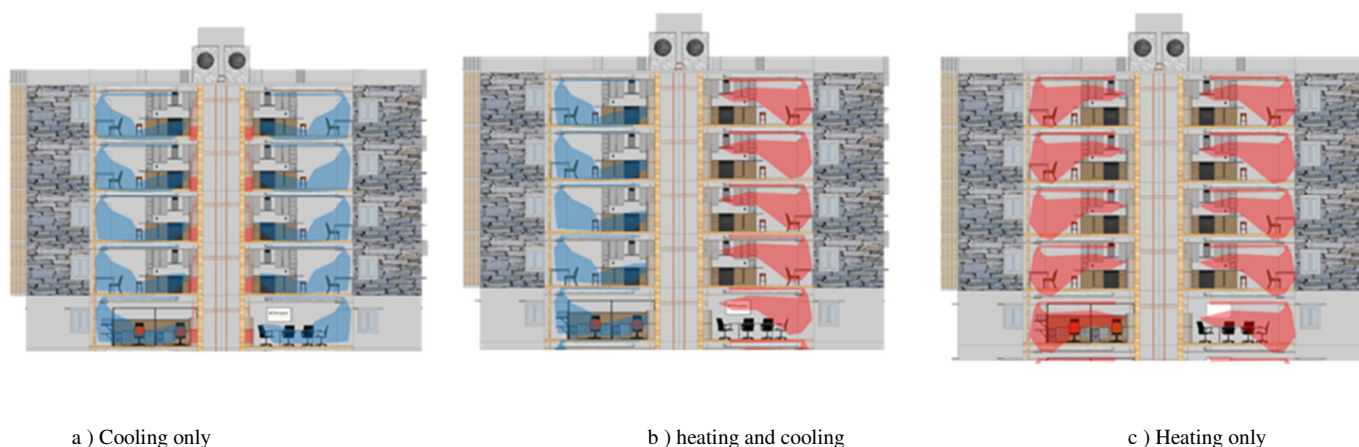


Fig. 7. Heat pump operation modes

By applying the heat losses reductions discussed in section 2.1 and comparing a conventional system against an individual heat pump being fed water at 30°C, there are savings at different levels.

A summary of annual energy is shown in Table 2 below.

Assumptions made are:

- Energy requirement is the total annual energy for both heating and hot water for all 55 apartments.
- Coefficient of performance taken at 6 for space heating and 4 for hot water preparation.
- Heat interface unit efficiency take at 90%.
- Heat generated in the plant room is generated in the same way in both cases.
- Distribution losses are for the improved insulation at medium load (Fig. 3)
- Conventional system at 80°C and heat pump source loop at 30°C

Table 2. Energy comparison between conventional system and heat pump solution

Energy for each solution and applications [kWh.]	Conventional system, with plant room feeding individual Heat Interface Units	Individual heat pump feed from low temperature loop
Total Energy requirement	4600	4600
Power input to the heat pump	n/a	942
Heat input to HIU / heat pumps	5111	3658
Distribution losses	2076	359
Heat energy generated in plant room to meet load	7187	4017
Total energy required (Heat + Electricity for heat pump)	7187	4959
Percentage Energy Reduction	-	-31%

The distribution loss are of course much lower (83% reduction) for the low temperature option compared to a conventional. The heat energy from the plant room is lower for the heat pump solution but Electric energy is required to run the heat pumps. This still make the heat pump option more energy efficient. These values are very conservatives and actual saving could be higher due to the following reasons:

- heating load will decrease in future and hot water usage become more significant which will lead to higher distribution losses on conventional systems
- the loop temperature of 30°C can be reduced to 20°C
- actual distribution losses on conventional systems are likely higher than calculated figures.

Further energy reductions are possible if heating and cooling loads are connected to the low temperature loop, because they negate each other and less energy needs to be produced in the central boiler plant.

3.1. Advantages & disadvantages of low temperature loop with heat pump

There are many advantages in using a very low temperature loop in combination with a heat pump in each individual dwelling of multi-family buildings:

- High system efficiency from reduced loop temperature, as shown in section 2.1.
- No over-heating problems from a low temperature loop reduces the use of additional cooling measures such as summer ventilation of corridors (see Figure 5 compared to Figure 7)
- Design flexibility allowing a combination of various sources in the plant room (Figure 6).
- Reduced capital expenditure for the developer as the overall heat demand is reduced and therefore smaller generators can be used
- The distribution network cost are reduced by changing from metal pipes to composite pipes, with possible reduced insulation levels.
- Overall system efficiency is less dependent on perfect workmanship for the loop installation due very low requirements on pipe insulation.
- Use of low temperature heat sources previously considered too low in conventional district heating
- Improved power to heat ratio if CHP plant are being used. Reducing output temperature means more electricity can be generated
- Reduced boiling and scalding risk
- When using individual reversible heat pumps, the load can be shared between heating and cooling thus reducing the load in the shoulder months and only requiring one loop for both heating & cooling.

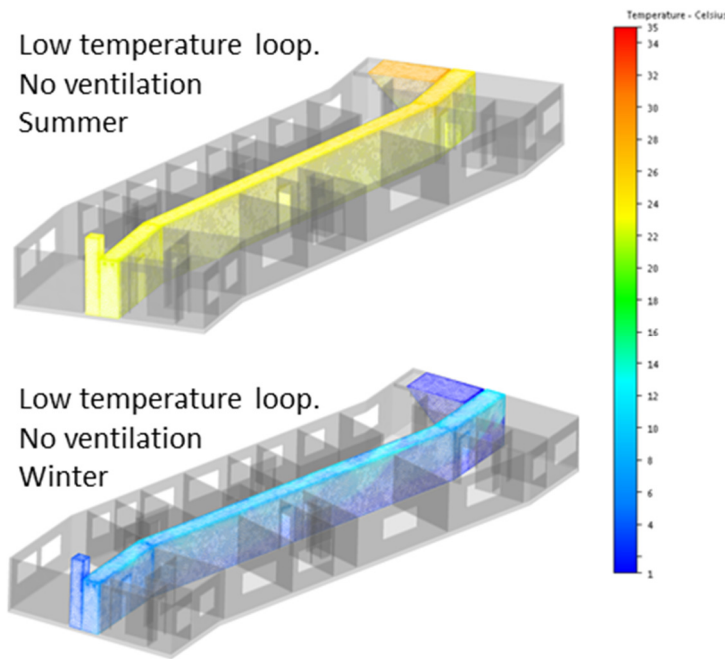


Fig. 8. Temperature profile in a corridor with very low temperature (20°C) loop

Disadvantages of the low temperature loop combined with an individual heat pump:

- Perceived difficulty to combine with existing high temperature District Heating network. Successful arrangement such as found in Denmark where high temperature transmission line mains and lower temperature distribution should be used to overcome this issue [2]
- The heat pump installed in the apartment uses more space than a conventional wall mounted heat interface unit. The case study also demonstrated that this problem can be overcome with a very compact heat pump/cylinder combination.
- The capital cost for the developer is usually higher for each individual dwelling. This additional cost will be offset by savings in the overall building. In heating only schemes the total costs for the scheme with the low temperature loop might still be higher, but in a heating and cooling scheme the overall costs for the entire system will be lower.
- The developers' general attitude to change, from a more conventional system to this kind of low carbon heating solution, might be an issue to overcome. Demonstration project would be required to convince them.
- The hot water & heat is generated in each individual dwelling instead of being fed from a centralized plant. This puts the maintenance regime on the individual rather than on the apartment block plant manager.

4. Conclusion

Heat networks are being promoted heavily in UK cities to develop networks to a level seen in other European cities. Heat pumps tend to be relegated to rural and suburban dwellings on the ground of limited space in the denser urban areas. The potential for heat pump should however be put forward to legislators and developers as this technology has benefits to offer. The combination of a low or very low heat loop with an individual heat pump is now a suitable solution in multi-family buildings thanks to the increase of energy efficiency and the resulting heating load reduction. When hot water becomes the main load in a dwelling, high temperature network are not as efficient as a localized hot water generation fed from a low temperature loop. Low temperature loops in multi-family dwellings also overcome the current overheating issues by reducing energy losses of distribution networks to almost zero and offer more flexibility in designing the distribution loop.

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