A Study into Ambient Loop Systems and Challenges Associated with Accurate Metering and Billing of the End Users

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Abstract

In order to reduce the operational energy consumption in heating and cooling of buildings and the industry are exploring methods of combining district heating and cooling networks with tenant's equipped with individual water source heat pumps. This has potential to create an ambient loop where tenants can exchange heat with each other, and a main source of heating or cooling can top up the energy demand of the loop. A challenge that arises in a system like this is how the landlord can accurately bill the tenants, when energy is shared between tenants via the landlord services loop. This study takes a theoretical approach on one potential solution where the billing software is able to use incoming data from energy meters and electricity meters, analyze the operational modes of the components in the system and proportion the energy usage accordingly.

Keywords: Ambient Loop, Heat Pump, Metering, Billing.

1. Introduction

Global warming and climate change is a fact. The International Panel of Climate Change can with 95% certainty say that humans are the main cause of the current global warming as stated in the IPCC report 2014 [1].

According to a study by Buffa et al [2], district heating and cooling network (DHC) technology is described as to be a promising solution to the problems such as local emissions and primary energy consumption in the heating and cooling industry of buildings.

Ambient loop systems for heat generation and distribution that predominantly use heat pumps as the primary source of energy, have great potential to reduce operational carbon emissions by utilizing the low energy technology that heat pumps offer in combination with low water temperatures which increases the efficiency of the heat pumps and decreases the energy losses in the distribution system.

Marquez et al. [3] investigated on how an existing district heating network could be adapted with the ambient loop, or 5th generation heat network. The study investigates the impact of connecting a 5th generation smart energy system with existing 3rd and 4th generation networks on performance of a system. In their study, a Combined Heating and Power plant was replaced by a heat pump and a 3rd generation network connected into a 5th generation network. The results clearly showed that there are potential benefits to the performance of a heat network with regards to performance. Their study also discusses the potential economic savings and identifies the increased revenues as a potential tool that allows network owners to reduce the energy bills to its customers with the potential long-term effects being tackling fuel poverty.

As a relatively new approach to heat generation and distribution in buildings, the deployment of ambient loop solutions come with a few challenges. One of these challenges is related to the accurate metering and billing of energy consumption from the ambient loop where energy injected into the ambient loop by landlord plant is coupled with continuous trading of energy between tenants using the ambient loop. Therefore, making it a challenge to accurately apportion the consumption of energy injected into the ambient loop by the landlord plant to the correct end users of that energy.

Traditional metering and billing methods cannot be applied for these applications, due to the complications that arise from continuous trading of energy between tenants are able to exchange energy with each other via the ambient loop. There's yet to be developed a functional and fully operating metering and billing system that is able to account for the energy trading between tenants. This study aims to explore a theoretical solution to accurately bill tenants that are utilizing an ambient loop system for heating and cooling energy.

2. Methodology of Accurate Meeting and Billing of the End Users

With a landlord owned ambient loop where the primary source of heating and cooling is a reversible air source heat pump, and each tenant connects to the loop with a dedicated reversible water source heat pump there are multiple points of energy consumption, that continuously changes. This requires carefully placed meters in the system, that communicates with the Buildings Management System which in turn sends the data to the cloud to a sophisticated billing software that produces the bill from the landlord to each tenant.

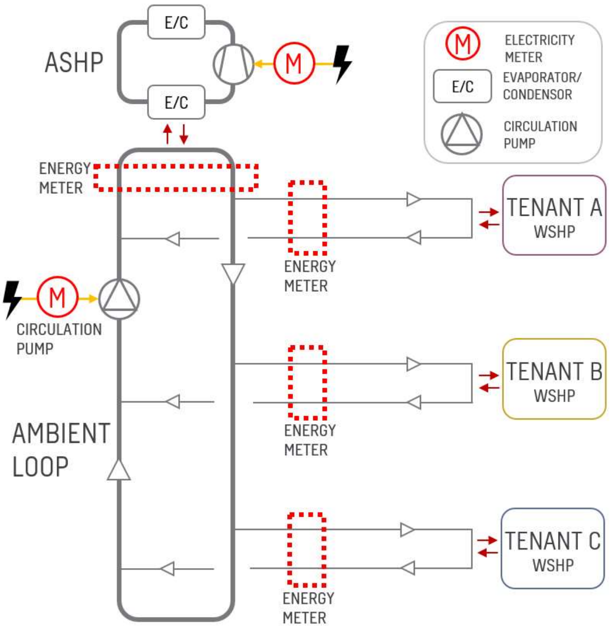

Fig. 1. System Schematic of Ambient Loop system with a main Air Source Heat Pump (ASHP) and individual Water Source Heat Pumps for tenants (WSHP).

Fig. 1 illustrates a schematic flowchart of the energy exchange system. Energy meters and electricity meters are indicated. Its data collected from these meters that will make up a part of the data in the billing software algorithm. The heat pump and circulation pump are metered for electricity usage and the ambient loop branch and tenant branches are metered for heat energy.

2.1. Billing Software Principles

The analysis begins with the tenants and data retrieved from the tenants metering stations. The meter sitting on the tenant's branches feeds information of the return temperature from the tenant to the loop as well as the volume flow rate. This data is then used in Equation 1 below for the billing software to calculate how much energy (|Q|) has been consumed by each tenant.

$$|Q_{tenant\ n}| = \dot{v} \times \rho \times c_p \times (T_{n1} - T_{n2}) \qquad (1)$$

Equation 1 describes the logic to obtain the energy usage form each tenant and the ambient loop for each time interval. The $\dot{v}$ (m^3/s) represents the volume flow rate at the measured data instance. For the tenant branches the volume flow rate will be constant, and the ambient loop flow rate will vary depending how many tenants are active. The density, ρ (kg/m^3) is data that is already programmed within the billing software. This data should be specific for the water temperature as the density will vary as a function of temperature. C_p (kJ/kgK) is the specific heat capacity for water and varies depending on the temperature of the water at the time it was measured. T_{n1} (°C) is the temperature of the flow for tenant N and is for this report set to be 30 °C constant. T_{n2} (°C) is the return temperature from the tenant to the ambient loop. In this methodology the value of T_{n2} takes a more theoretical approach than what will actually be working in practise and an arbitrary temperature is used in calculations.

Depending on current mode of the heat pump, Q (kW) can be either negative (cooling mode) or positive (heating mode), hence the function in Equation 1 is set up to only calculate the absolute value of Q. The software should be able to identify and log the mode of all heat pumps for the current interval. This is of essence for the next step in the analysis, when the energy usage of the main heat pump is proportioned by the tenant heat pumps that uses it.

A similar exercise for calculating the energy consumption in each tenant branch will be undertaken for the main air source heat pump. In an operating system, the return temperature of the loop will be measured, and the energy consumption of the main air source heat pump will be calculated by using proportionating balance theory. As this methodology is taking a theoretical approach and no temperatures and flow rates has been measured, the following analysis will be made with regards to the main air source heat pumps energy consumption.

$$Q_{ASHP} = Q_{tenant\ A} + Q_{tenant\ B} + \cdots + Q_{tenant\ n} \qquad (2)$$

$$T_{return,loop} = T_{flow,loop} - \frac{Q_{ASHP}}{v \times \dot{\rho} \times c_p} \qquad (3)$$

Equation 2 calculates the energy consumption Q_{ASHP} (kW) that the main air source heat pump requires in order to provide to the loop after the tenant's energy exchange has been completed. If the value of Q_{ASHP} is a positive value, this means that the ambient loop requires heating energy from the main air source heat pump, as it is heating energy that has been taken from the loop by the tenants (after the heat exchange between tenants has been conducted). If Q_{ASHP} is a negative value, this means that the ambient loop temperature has increased in temperature and requires cooling from the main source heat pump as the tenants are cooling their spaces and discharging heat into the ambient loop.

Equation 3 calculates the return temperature of the ambient loop. In an actual operating system, this value will be a measured value and the equation and results is taken into the scope to demonstrate completeness of the energy analysis.

Once the energy consumption Q is calculated for all tenants and the main air source heat pump, the analysis of which tenants are in cooling and heating mode has been undertake, the following step is for the software to identify for each for the tenant heat pumps whether they are operating in the same mode or not as the main heat pump. All tenant heat pumps that operates in the same mode as the main heat pump will be part of the proportioning of energy for the certain interval. If the tenant heat pump is not in the same mode as the main heat pump, this means that this tenant currently takes advantage of the loop and will not be part of the proportionating.

Using Equation 4, the proportion is calculated as the ratio between the current tenant's total energy consumption for the current interval over the total energy consumption by tenants in the same operational mode. Also, under the condition that the main heat pump operates in the same mode. If not, the tenant proportion is zero.

$$Tenant\ prop.main\ ASHP = \frac{|Q_{tenant\ n}|}{|Q_{tenant\ A}| + |Q_{tenant\ B}|\ + \dots + |Q_{tenant\ n}|} \quad (4)$$

Similar logic is applied to the proportioning of heating and cooling energy, the electrical energy consumed by the circulation pump of the ambient loop will also be proportioned over the tenants using it. The difference in the calculation of circulation pump apportioning is that regardless of if the tenant heat pump is in the same operational mode or not as the main heat pump. This is because regardless of if the tenant is exchanging heating or cooling with the loop, the tenant uses the loop at the circulating water and therefore this is part of the accurate bill.

$$Tenant\ prop.\ circulation\ pump = \frac{|Q_{tenant\ n}|}{|Q_{tenant\ A}| + |Q_{tenant\ B}|\ + \dots + |Q_{tenant\ n}|} \quad (5)$$

The tenant's calculated proportions are then multiplied with the measured energy consumption for the main heat pump and the circulating heat pump. The result of this is multiplied with the time interval and cost of electricity at the moment of the meter reading. All this data is then added together for a monthly accurate bill for each tenant.

2.2. Results

The result of this study is to present a methodology for an accurate metering and billing system for an ambient loop system where tenants connect to the ambient loop with dedicated water source heat pumps. The system allows the tenants to exchange energy with each other via the ambient loop, and if required a main air source heat pump provides additional heating or cooling to the loop.

Table 1. Bills produced for one hour of operation

	Main ASHP £	Circulation Pump £	Total £
Landlord's bill	0,025	0,275	0,300
Tenant A bill	0,012	0,125	0,138
Tenant B bill	0,006	0,08	0,086
Tenant C bill	0,006	0,069	0,075

Table 1 shows the summarized bills of Tenant A, Tenant B and Tenant C is the same value as the bill that the landlord received from the utility company.

3. Conclusion

The methodology and results detailed within this study will contribute towards on-going research and development in the building's services industry associated with accurate metering and billing of ambient loop systems.

The methodology and results detailed within this study, demonstrate application of a metering and billing solution to an ambient loop system condensed down to three tenants that are served by a main landlord heat pump. However, the same approach applies regardless of quantity of tenants using the ambient loop.

The methodology and results focus on a theoretical analysis of how the tenants use the ambient loop for one hour. For the purposes of this analysis, various operational modes are assumed during the selected time period. The results show the final bill for the tenants and the landlord for the one-hour period, accurately metered and billed.

This study demonstrates one possible approach to achieving an accurate metering and billing strategy for an ambient loop system. This could bring potential savings in carbon, energy and economic aspects; however, this study only analyses one of many opportunities to do so. This study helps the industry to understand that the ambient loop system is a potential way forward towards achieving net zero carbon, however, in order to understand the full benefits of the system, more extensive and holistic life cycle analyses need to be undertaken.

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References

[1] IPCC (2014) *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)].*

[2] Baratieri, M., Buffa, S., Cozzini, M., D'Antoni, M. and Fedrizzi, R. (2019) 5th generation district heating and cooling systems: A review of existing cases in Europe, *Renewable and Sustainable Energy Reviews,* 104, pp.504-522.

[3] Dunham, C., Lagoeiro, H., Jones, P., Maidment, G., Marques, C., Matabuena, R. and Revesz, A. (2020) *Integration of High Temperature Heat Network with Low Carbon Ambient Loop Systems*. Available from: https://openresearch.lsbu.ac.uk/download/be0db9d8b81a6363536871d3609075df878af825b76ee7b28e8c7bc5d50764c0/1381561/Integration%20of%20high%20temperature%20heat%20networks%20with%20low%20carbon%20ambient%20loop%20systems.pdf [Accessed 18 Feb. 2022].