Modeling of Low Temperature Thermal Networks Using Historical Building Data from District Energy Systems

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Abstract

A Modelica library for modelling and comparing District Energy Systems (DES) and Low Temperature Thermal Networks (LTTN) has been developed. The library consists of six unique models and a series of replaceable sub-models that allow for different scenarios for thermal energy generation.

District Energy Systems have historically been implemented in areas with high heating demand and/or cooling to increase energy efficiency due to the utilization of larger industrial generation stations. These systems use a centralized Energy Management Center (EMC) that heats and/or cools a thermal transport fluid to a set temperature before distributing the conditioned fluid to different buildings within the community using a piping network. Traditionally these piping networks consist of four pipes, a supply and return for heating and a similar two for cooling. Although these systems have proven effective, increased awareness of the effects of greenhouse gases has spurred research interest in developing more efficient thermal microgrids.

One promising manifestation of a District Energy System is a Low Temperature Thermal Network. Low Temperature Thermal Networks replace the two fluid, four-pipe system present in traditional District Energy Systems with a singular low temperature working fluid. Like District Energy Systems, this low temperature fluid is supplied to buildings within a community using a thermal network which interfaces with each building through an Energy Transfer Station (ETS). Traditionally these ETSs consists of a heat exchanger that interfaces between the building's HVAC system and the thermal loop.

LTTNs differ from traditional systems because they also require the use of heat pumps at ETSs to transfer energy to and from the building and meet the internal building temperature set point. The benefit of this is that the low temperature of the thermal loop allows for a higher level of thermal energy capture from waste energy sources within the community and thus allows for greater system level energy utilization. For example, heat could be captured from cooling operations, off-setting the need for additional thermal energy generation. A consequence of this LTTN is that each of these heat pumps will create an additional electrical load.

In order to determine the net benefit of this energy recovery when weighed against the additional electrical loads, a Modelica library was created to model both DESs and LTTNs. This library was then validated against a nine-building district energy system located in a high-density community within Southern Ontario, Canada. To accomplish this real-world data was gathered on a DES, including the pipe layout, pipe geometry and equipment efficiencies. Additionally, historical building data from the community was gathered at five-minute intervals and was used to tune the model's predicted generation of the system, against that of the actual facility.

An analysis was then performed to compare the performance of an existing, operational four-pipe DES against an alternative design that consists of two one-pipe LTTNs. This comparison was done during a two-week period in the transitional season of October, during which the community experienced 52.96 MWh of thermal demand with approximately half of the demand being heating loads and the other being cooling. By simulating the system with the Modelica library, the results showed that the LTTN can drastically reduce the system's natural gas usage and reduce carbon emissions by over 90% while utilizing 34% less energy than the traditional district system. These reductions were the direct result of the LTTN's ability to capture waste energy within the community during this period of mixed loads. Although the LLTN led to a 55% increase in peak electrical demand, the unique capabilities for thermal energy sharing within a LTTN shows promise for greater levels of energy utilization and improved system level efficiencies.

Keywords: thermal microgrid, district energy, thermal transport systems, carbon emissions