COMMERCE DEPARTMENT
DIVISION OF ENERGY RESOURCES

Retrofitting standard efficiency furnaces: A new path to high efficiency heating and humidification?

Space heating is the number one end use for energy in Minnesota buildings, and residential forced air furnaces consume more energy for space heating than any other type of heating device. To date, the only way to increase the efficiency of a natural gas forced air heating system has been to replace it with a higher efficiency (90%+) model.

The Center for Energy and Environment received a CARD grant to investigate an alternative to furnace replacement as a way to achieve high efficiency space heating—an upgrade to residential standard efficiency furnaces called the transport membrane humidifier (TMH). The TMH saves energy by increasing the efficiency of induced draft furnaces from 76%-82% to the 90%+ efficiency level typically associated with condensing furnaces. The TMH extracts additional energy from the combustion process by recovering water vapor and waste heat from the furnace flue gas to preheat and humidify the inside (return) air. The study explored the potential energy savings and comfort benefits while also characterizing the risks associated with increasing humidity levels and retrofitting existing equipment.

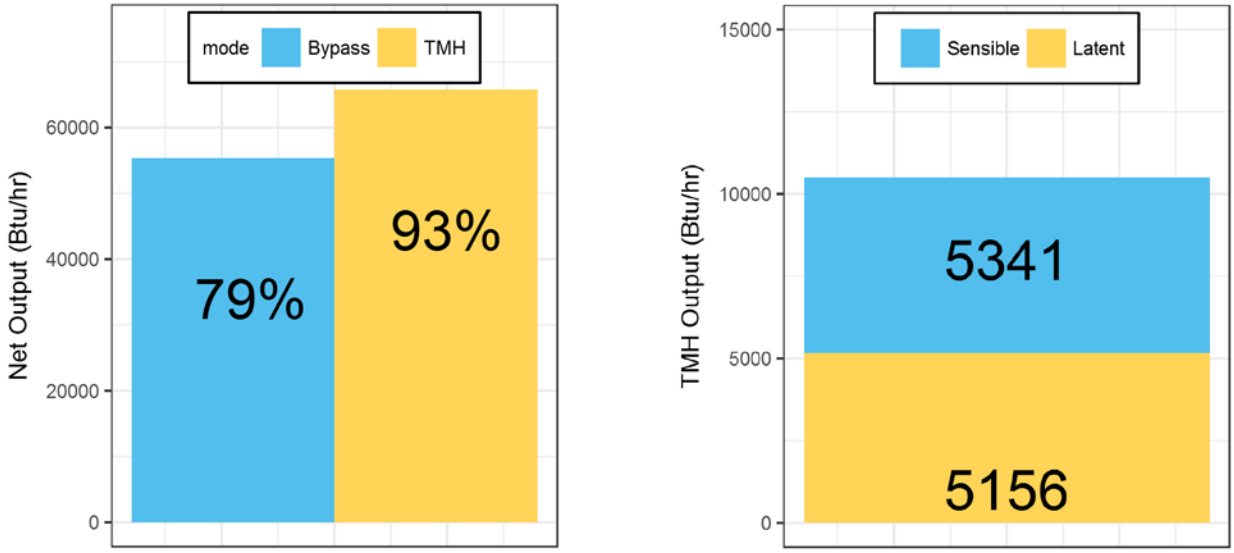
TMH devices were installed and instrumented in four sites (Figure 1). Performance was continuously monitored to facilitate a comparison between baseline furnace operation and TMH operation. During bypass (baseline) mode, flue gases escaped via the regular induced draft vertical vent and the TMH unit and its controls were disabled. The ambient temperature and relative humidity were monitored at three locations per site to determine the effect of TMH operation on the indoor environment.

Figure 1. TMH device installed in one of the test sites

Energy Savings

TMH units extract additional sensible and latent energy out of the flue gas to preheat and humidify the furnace return air. Across all four sites, the average furnace output increased by 10,500 Btu/hr, and steady state furnace efficiency improved from 79% to 93%, yielding an average improvement (or gas savings) of 18% as shown in Figure 2(a). Without humidification, the improvement in space heating was 9%. These figures translate directly into annual natural gas savings.

Figure 2: (a) Average furnace output and air side efficiency for baseline furnace operation (bypass) and TMH operation; (b) average sensible and latent energy outputs (Btu/hr) of the TMH.



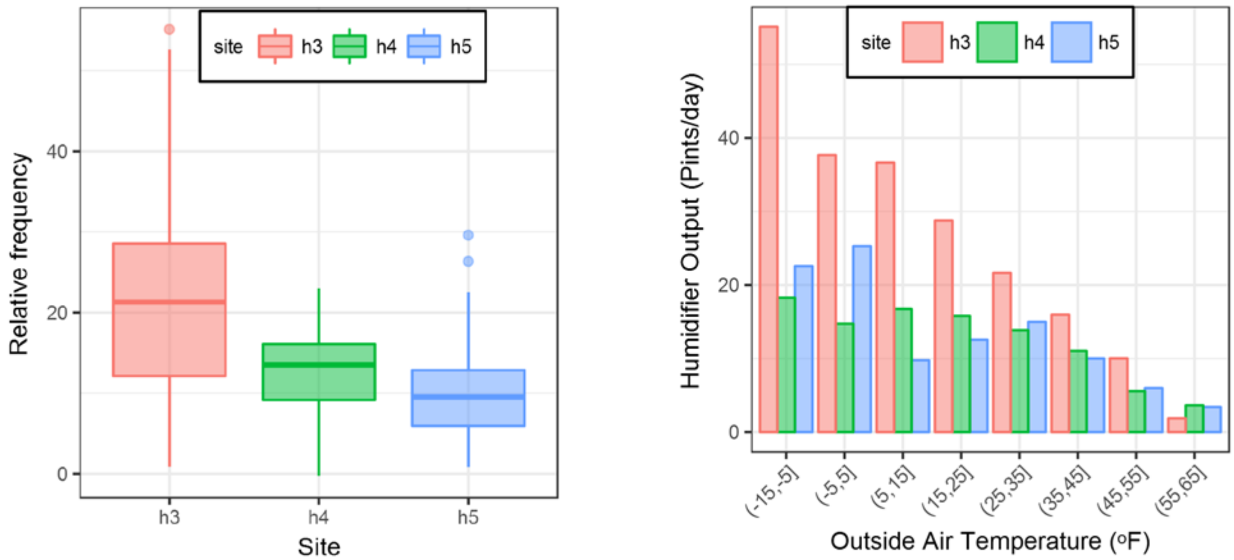
In Figure 2(b) the added furnace output is broken down into the average sensible and latent energy outputs of the TMH unit. The bulk of the energy (~80%) is added to the airflow via the furnace. An additional 5,300 Btu/hr is added to the TMH to increase the temperature of the return air delivered to the furnace heat exchanger. The TMH also adds 5,200 Btu/hr of energy by increasing the moisture (absolute humidity) of the return air flow delivered to the furnace heat exchanger.

The cost-effectiveness of TMH retrofits varies substantially. Over several scenarios, including variations in the cost of natural gas and savings found in this study, real natural gas savings vary between $46 and $189 per year for heating savings and between $83 and $342 for heating and humidification savings. In the nominal scenario, heating-only savings are expected to vary between about $57 and $126 per year. The simple payback of units depends on the anticipated savings compared to the initial cost. Based on measurements in this project and prior capital cost estimates, costs are projected to range from about $1,400 to $1,900, which is about 60% less expensive than a high efficiency furnace replacement. Modeled scenarios suggest a wide range of simple payback periods. Under most nominal scenarios, the TMH is expected to be cost-effective over its lifetime, with end-user simple payback periods ranging from 7 to 15 years. As incentives are added for heating and humidification, payback periods can fall to less than 10 years for heating-only savings and less than 5 years for heating and humidification savings.

Humidification

Whether or not the humidification output is characterized as energy savings, the TMH operates as a whole-house humidification system. In contrast to typical humidifiers, the TMH only adds moisture when the furnace is running. Therefore, the humidity output is proportional to the runtime of the furnace (i.e. the heating load). Median outputs for these sites varied between 10 and 21 pints/day, as shown in Figure 3(a). Daily outputs ranged on the low end between 6 and 12 pints/day up to 16 to 29 pints/day on the high end. These average daily outputs are in line with typical whole-house humidifier capacity. As can be seen by the higher rates from site h3, humidity output will be relatively larger for furnaces that are more accurately sized for design load (e.g. have higher runtime). One desirable characteristic of the TMH is that humidity output is proportional to the humidification demand; the TMH outputs more humidity during cold, dry weather as shown in Figure 3(b).

Figure 3: (a) Range of TMH humidifier outputs for each site; (b) TMH humidity output increases with decreasing outside air temperature



The most significant task in this study after the validation of TMH performance was the assessment of the impact on the indoor environment. The potential for excess humidification from the introduction of an indirectly controlled humidifier system raised concerns about indoor air quality, the potential for microbial growth, and the long-term impacts of increasing wintertime humidity. However, excess humidification was not observed in sites experiencing a wide range of baseline relative humidity, from less than 20% to over 60%. During cold weather (below freezing), the TMH increased indoor relative humidity by 5% to 10%. Above freezing, the TMH output was significantly reduced due to low runtimes (output) compared to the rate of humidity exchange with the environment. Sensors placed in structural lumber also showed that the increased humidity levels from TMH operation did not impact the seasonal drying cycle of the homes.

The TMH is a viable technology for achieving large natural gas savings for space heating in single-family homes. It is the only viable alternative to a condensing furnace upgrade and it is the cheaper option, particularly for the vast number of standard efficiency furnaces that will remain operational over the coming decades, which number in the hundreds of thousands. Still, the TMH is a pre-commercial technology that has not yet been taken up by a manufacturer for commercialization, and this current status remains the major barrier to adoption. Even under a fast transition to high-efficiency heating in the state, there remains a decade or more over which these barriers may be resolved and the TMH introduced for consequential energy savings and emissions reductions.

Read the full report, "Retrofitting 80% Residential Furnaces for High Efficiency," for complete details on the results. For more information, contact project manager Mark Garofano or CARD program administrator Mary Sue Lobenstein.