Benefits of Reduced Diameter Copper Tubes in Evaporators and Condensers

Robert Weed
Copper Development Association

John Hipchen
Exel Consulting Group

ABSTRACT

Demands for higher energy efficiencies in both residential and commercial refrigeration and air conditioning systems have resulted in a trend toward coil designs that are more compact with higher capacities for heat transfer. Traditional copper tube / aluminum fin coil manufacturing technology remains prevalent throughout the industry and, when modified for smaller diameter copper tubes of 5mm (0.20 inches) or less, significant improvements in heat transfer can be achieved. Coupled with internal enhancements to the copper tubes such as microgrooves, condenser and evaporator designs can be smaller, more efficient and operate at higher pressures to accommodate new refrigerants. Higher efficiency coils require less space and can help lower costs related to the overall packaging of a refrigeration or air conditioning system.

This paper demonstrates the impact of smaller diameter copper tubes and compares heat transfer results with common tube diameters of 7mm and above. Both simulated and actual performance data is shown as well as energy-efficient design options that are available with smaller diameter copper tubes.

Copper components also offer antimicrobial properties and these advantages are discussed. In many air conditioning and refrigeration applications, the growth of bacteria and microbes is a concern. Data from bacteria studies is shown that supports the use of copper components where antimicrobial properties are required. Recent registration of copper alloys with the U.S. Environmental Protection Agency is discussed as well.

INTRODUCTION

This paper discusses round copper tube, flat fin coils. These coils can be seen in a number of applications that cover residential, commercial and industrial settings. Typical components are condensers, evaporators and water heating coils. The history of round tube, flat fin coils dates back over 100 years and today, they are being successfully modified to fit modern demands.

Heat transfer engineers face increasing requirements for energy efficiency and a push to use refrigerants that are less damaging to the atmosphere. In an effort to lower costs, there are demands for smaller, more compact systems that save on materials and refrigerants. Smaller diameter, internally enhanced copper tubing referred to as "MicroGroove™" tubes, can meet these demands with minimal investment or change to well established manufacturing practices.

Recent studies and documented trials show that reducing the diameter of copper tubes improves heat transfer resulting in more energy efficient, smaller and lighter coils. Additional benefits to the manufacturers and distributors of air conditioning and refrigeration systems include reduced refrigerant charge and less material. These benefits are not only associated with meeting energy and refrigerant regulations, but also reduce costs in an increasingly competitive market.

In the 1980's, tubes with internal grooves and enhancements were developed. Because these internal modifications were found to have such a big impact on efficiency, they quickly became common in the market. The name MicroGroove™ today refers to these internal enhancements and also refers to smaller diameter tubes. Over the past 10 years, a trend has emerged toward internally enhanced smaller diameter tubes. Coils with MicroGroove tubes have been in commercial use since approximately 2005. Factors behind the move toward small diameter tubes range from government mandates on energy efficiency such as increased SEER ratings, to the phasing out of R22 refrigerant and the higher pressures that are associated with replacements for R22. The coefficient of performance, or COP, is another rating that design engineers are paying more attention to and the drive to increase COP is yet another factor behind trends toward smaller diameter tubes.

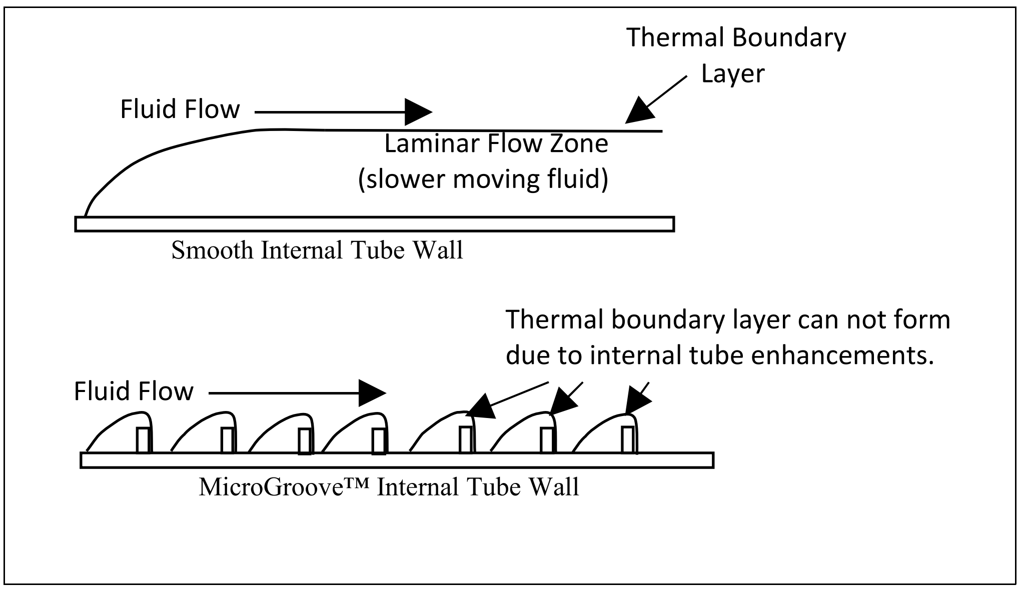
Robert Weed is Vice President of OEM at the Copper Development Association. John Hipchen is President of Exel Consulting Group.

Government regulations became a larger factor in the design of air conditioning and refrigeration equipment when the Montreal Protocol took effect in January of 1989. The Montreal Protocol mandated a phase-out plan for CFC (chlorofluorocarbon) refrigerants by 1995, including R12. HCFC (hydro chlorofluorocarbons) refrigerants were allowed as transitional replacements until HFC (hydro fluorocarbon) refrigerants are fully implemented. HFC refrigerants do not contain chlorine which has been linked to the depletion of our ozone layer. It is typical for HFC refrigerants to operate at higher pressures than CFC or HCFC refrigerants. Government mandates related to energy efficiency and refrigerant continue to push air conditioning and refrigeration manufacturers toward new coil designs that must be more efficient and handle higher pressures.

BOUNDARY LAYERS AND THEIR EFFECT ON HEAT TRANSFER

As fluid moves through a tube, the fluid closest to the tube wall behaves differently than the fluid in the center of the tube. The fluid next to the tube wall sets up a boundary layer where heat transfer becomes more difficult. This applies to the hydraulic motion of fluid, as well as the way heat moves from the center of the tube to the tube wall. Therefore, heat transfer engineers refer to both hydraulic boundary layers and thermal boundary layers. To simplify, fluid closest to the tube wall tends to move slower than the fluid in the center. Even in turbulent flow, a laminar sub-layer forms and heat moves slower through these boundary layers than it does in the faster-moving fluid toward the center of the tube. Boundary layers act as an insulator and interfere with heat transfer.

The internal enhancements in MicroGroove tubes reduce boundary layers for all types of fluids flowing through the tube, including liquids, gasses and mixtures of the two. Regardless of refrigerant type, the internal enhancements reduce boundary layers and increase heat transfer through the tube wall.

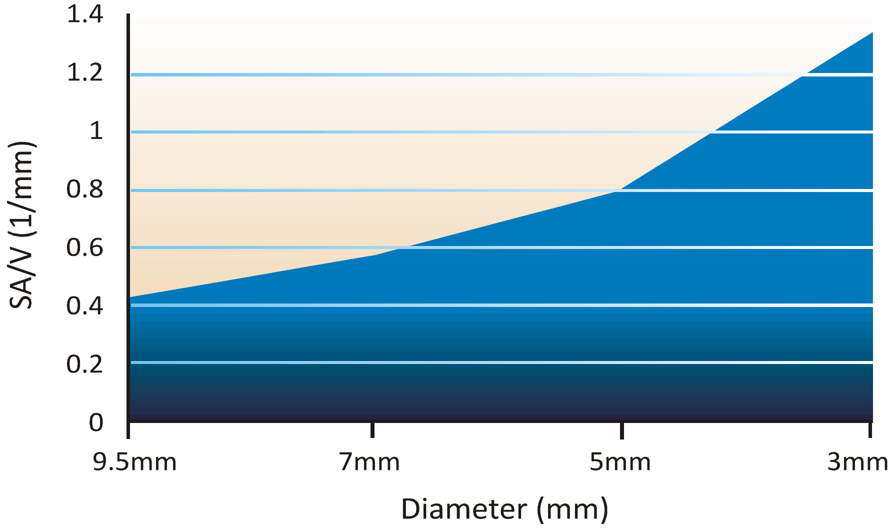


The illustration above shows that the boundary layer develops in a tube with smooth internal walls and does not dissipate. In a tube with MicroGroove internal enhancements, the boundary layer begins to develop, but quickly breaks down as it moves over the grooves. The exact configuration of internal grooves and patterns is based on a long history of technical development and design by tube manufacturers. The additional mixing of refrigerant that occurs inside the tube because of these grooves increases the amount of refrigerant that comes in contact with the tube wall. The positive effect on heat transfer from these internal enhancements has been known for a long time and applied commercially for over 20 years. When the benefits of internal tube enhancements are combined with small diameter tubes, the resulting design advantages can be used to reduce coil size and improve performance efficiencies.

TUBE GEOMETRY AND ADVANTAGES OF SMALL DIAMETER TUBES

When comparing tubes of different diameters, it takes several smaller diameter tubes to equal the same internal surface area of a larger diameter tube. The result is an increase in the surface area to volume ratio which improves heat transfer. Because of the increased heat transfer in smaller diameter tubes, the same amount of cooling can be achieved without matching the volume or surface area of the larger tube. In addition to increased heat transfer, a smaller diameter tube can hold the same pressure as a larger diameter tube and accomplish this with thinner tube walls. As a result, coils made with smaller diameter tubes can reduce the weight of the materials being used and in turn, reduce costs.

Surface to Volume Ratio



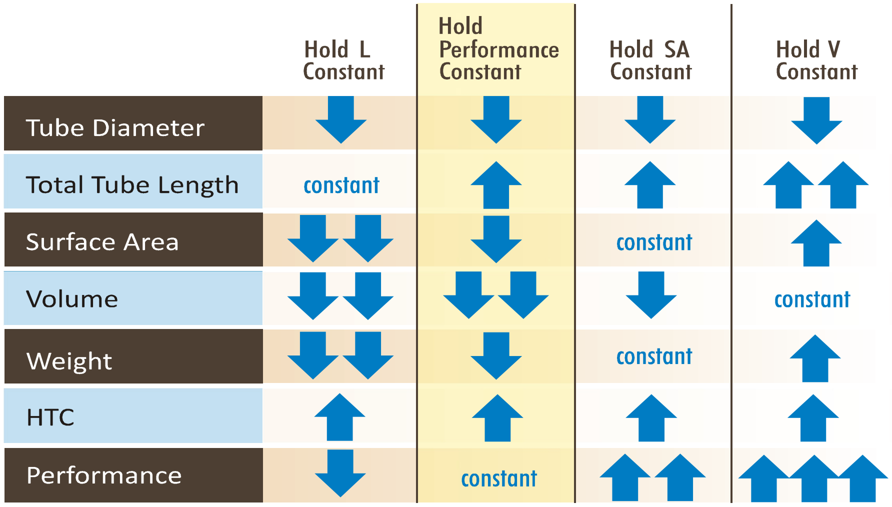
A plot of the internal surface area of a tube over internal volume shows that as tube diameter is reduced, the amount of surface area that is available in the same volume increases dramatically. With reduced tube diameters, more surface area is available to transfer heat.

Effects of Reducing Tube Diameters

For the engineer designing coils, there are a number of design parameters that can be modified such as; tube diameter, number of tubes and total length of tubes. These parameters will affect the amount of surface area, refrigerant charge, weight of the coil, heat transfer coefficients and overall performance.

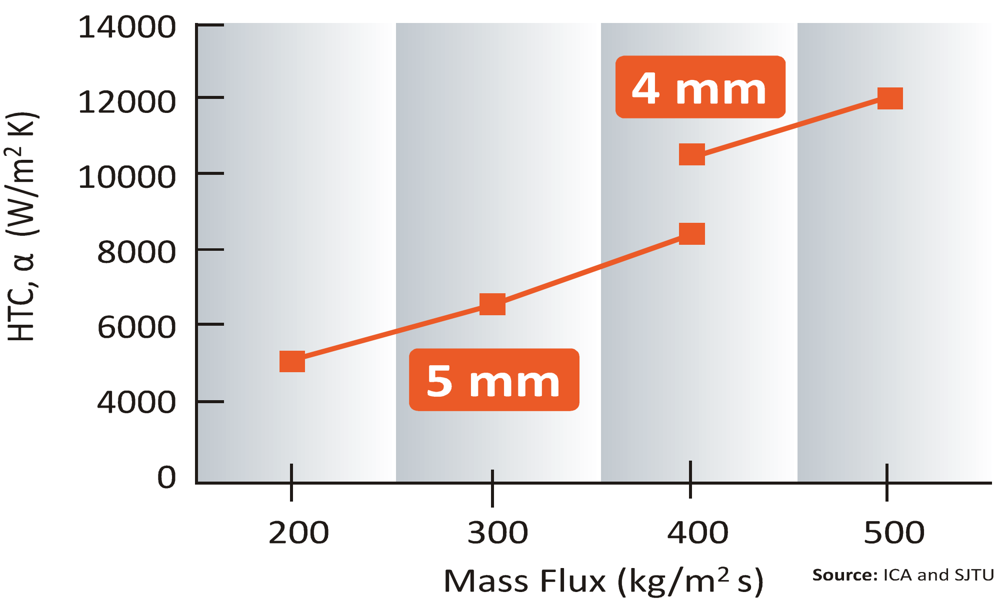
The chart below shows the effects on design parameters when tube diameters are reduced in a known coil with known performance criteria. This chart shows the following scenarios:

- Constant Total Tube Length – In a coil with reduced diameter tubes but the same total tube length, there is a decrease in surface area, volume and weight. The heat transfer coefficient increases but the drop in surface area is such that the system can not match the performance of the original coil. This would amount to considerable cost savings due to the low refrigerant charge and reduced materials, but depending on the application, the drop in performance is likely to be deemed unacceptable.
- Constant Performance - A coil with reduced diameter tubes but the same performance will require an increase in the total tube length. There will be considerably less surface area than the original coil and also less volume, less weight and a higher heat transfer coefficient. This scenario represents a coil that matches the performance of the original, but is smaller, lighter, has a lower refrigerant charge, and will have a significantly lower cost.
- Constant Surface Area - In the third column, the surface area is held constant resulting in increased total length of the tubes. If the smaller diameter tubes have the same tube wall thickness as shown in this chart, the weight is approximately equal. If the smaller diameter tubes have typical reduced wall thicknesses found in supplier's product catalogs, the resulting coil will have a lower weight than the original. The volume will decrease and the heat transfer coefficient increases due to increased tube efficiency. In this scenario, performance increases considerably and costs are reduced because there is less refrigerant.
- Constant Volume - In a coil with reduced diameter tubes but the same volume, the total length of the tubes will increase more than the other scenarios, the surface area increases and so does the weight and heat transfer coefficient. In this scenario the performance goes up dramatically. Although a cost increase would be expected due to increased use of materials, a significant increase in performance will be gained.



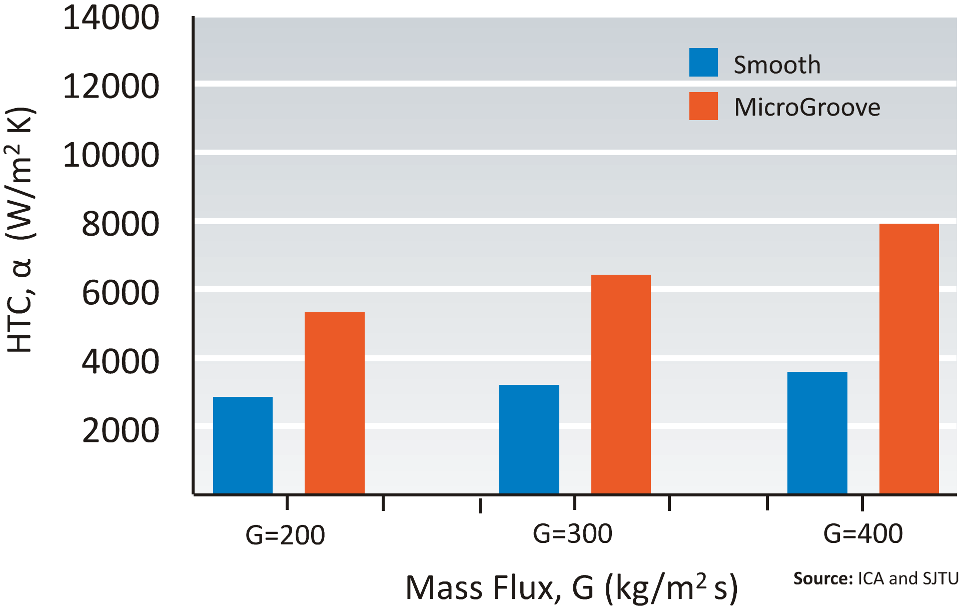
EXPERIMENTAL RESULTS WITH SMALL DIAMETER COPPER TUBES

Local Heat Transfer Coefficient for MicroGroove Tubes



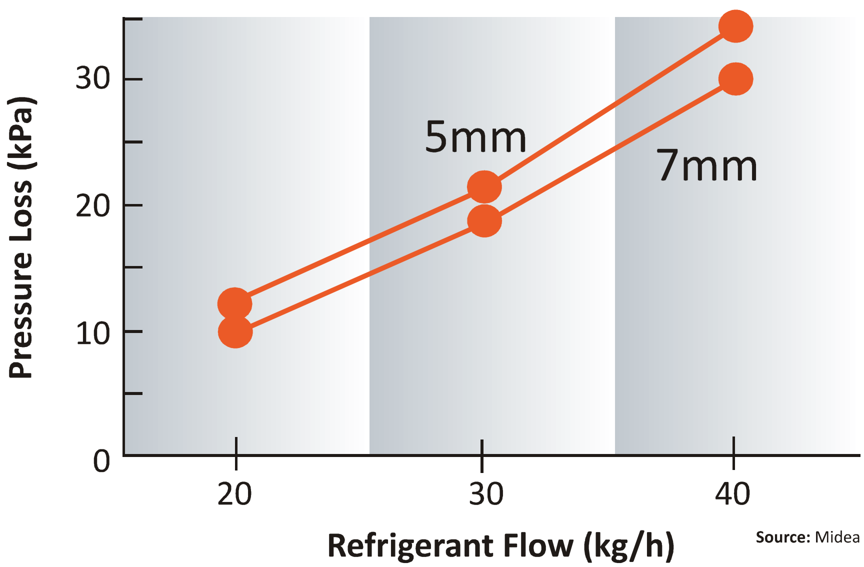
Above, the heat transfer coefficient is measured for 5 mm and for 4 mm MicroGroove tubes in a condenser using R410A as a refrigerant. Note that mass flux is defined as mass per area per time. Only the tubes were modified in this experiment leaving fins and external conditions constant. The higher heat transfer coefficient can be seen in the 4 mm tube. This phenomenon of increased heat transfer coefficient in smaller diameter tubes can be replicated with other refrigerants.

Heat Transfer Coefficient for Smooth and MicroGroove Copper Tubes, 5 mm Diameter



The effect of grooves and internal tube enhancements on the heat transfer coefficient can be seen above, measured in 5 mm tubes at three different mass flux rates using R410A refrigerant. The effect on the heat transfer coefficient when compared to a smooth internal tube surface is rather significant, as seen in this data.

Refrigerant Pressure Loss Increases as Tube Diameter Decreases



Pressure loss is plotted above, measured in an evaporator core with 7 mm tubes and one with 5 mm tubes. The refrigerant in this experiment was R410A. At three different flow rates, a slightly higher pressure loss can be seen in the smaller diameter tube. Pressure losses can be easily reduced with increased number of branches and reduced tube length per branch.

CASE STUDY: LU-VE, S.p.A., Italy

In an effort to optimize an existing condenser with conventional 9.52 mm tubes, the Italian company LU-VE, S.p.A. designed new coils keeping the performance at approximately 20 kW for each coil. Aluminum multichannel tubes and copper MicroGroove tubes of 5 mm diameter were used in the trial coils. All external conditions such as fin design and fin pitch remained constant. The refrigerant charge was reduced in the aluminum tube design to 51% of the refrigerant used in the existing design. However, the 5 mm copper tube design only used about 44% of the refrigerant in the original design, further reducing the refrigerant charge another 16.7%. Note the header required in the aluminum design was 38 mm, which the company reported as the minimum diameter they could use to ensure proper tube-to-header joints and refrigerant flow.

Case Study: LU-VE, S.p.A., Italy

Model	Current Design	Copper - Special 5 mm Tubes	Aluminum - Multichannel Tubes
Capacity (kW)	19.6	20.2	19.5
Tube Diameter (mm)	9.52	5.0	30 x 2
Tube Volume (dm^3)	5.15	2.04	190
Header Volume (dm^3)	0.36	0.36	0.91
Total Coil Internal Volume (dm^3)	5.51	2.41	2.81
Header Diameter (mm)	22	22	38
Internal Volume Difference	100%	43.6%	50.9%
Internal Volume Difference	229%	100%	116.7%

ANTIMICROBIAL PROPERTIES OF COPPER

Copper alloys have documented antimicrobial properties and coupled with highly efficient heat transfer, evaporators made with copper offer the industry a potential solution to problems caused by microorganisms. Air temperature in buildings is regulated by heating, ventilating and air conditioning (HVAC) systems comprised of compressors, fans, ductwork, condenser coils and evaporator coils. The dark, humid environment in which the air handling components of an HVAC system operate is ideal for the growth of fungal, bacterial and viral organisms. These organisms are the primary cause of unpleasant odors and some microorganisms are pathogenic, responsible for various illnesses. Organisms growing inside air handling systems are easily disseminated into the living spaces in buildings and homes. The resulting poor air quality can cause acute symptoms such as sore throat, ear and nasal infection, headache, and even life-threatening infections such as pneumonia. Various studies by health and safety authorities such as the U.S. Environmental Protection Agency (EPA) and the National Institute for Occupational Safety and Health (NIOSH) have determined that pathogens distributed by air handling systems can lead to a condition known as "Sick Building Syndrome" (Mendall et al, 2003). In their 1989 Report to Congress on Indoor Air Quality, the EPA estimated that "tens of billions of dollars per year" are lost as a result of poor air quality.

Laboratory testing has shown that surfaces made of copper and copper alloys kill or inhibit fungi, bacteria and viruses (Michels et al 2007, Noyce et al 2006a, 2006b, 2007, Weaver et al 2008, 2009, Wilks et al 2005). Years of testing has led to the registration of copper alloys with the U.S. Environmental Protection Agency as antimicrobial agents, acknowledging copper alloys' ability to continuously kill various species of bacteria. Weaver, Michels and Keevil demonstrated that copper killed fungal spores while aluminum had no effect. Copper also prevented germination of spores, thereby reducing the risk of spore release. In addition to effectively inhibiting fungi and bacteria, copper alloys also inactivate viruses, including Influenza A. Noyce et al reported that copper samples inactivated 75% of Influenza A in one hour and 99.99% after six hours.

The potential health benefits of copper are complimented by its superior heat transfer capabilities. Compared to aluminum, copper HVAC components can potentially improve system efficiency and life. Oxide layers and microorganisms growing on heat exchanger fins can impede air flow, reduce heat transfer and reduce the overall efficiency of the HVAC system. With minimal corrosion and negligible growth of biofilm on critical heat transfer components, air flow through a copper alloy heat exchanger is maintained at or near design levels.

To demonstrate the potential impact of copper HVAC components on indoor air quality and energy efficiency, several trials funded by the U.S. Department of Defense under the auspices of the Tele-medicine and Advanced Technology Research Center (TATRC) are underway.

Copper Air Quality Project - Overview

The copper air quality project is a joint project funded by U.S. Army Medical Research and Material Command. This project includes participants from universities, industry and associations. The research study consists of three parts: air quality in a laboratory setting, air quality at operational sites at Fort Jackson, South Carolina and energy efficiency monitoring at Fort Jackson. The intent of the Copper Air Quality Program is to design, produce and evaluate copper components for HVAC systems in order to demonstrate the effectiveness of copper surfaces for reducing exposure to harmful microbes within these systems and throughout the living space they serve.

Copper Air Quality Project - Methodology

The objective of the lab study is to perform experimental comparisons of microbial growth in HVAC systems using copper versus aluminum heat exchangers and drip pans. These experiments are being carried out in a test system allowing pilot-scale simulation of a building air conditioning system (Figure 1). This avoids the unrealistic aspects of environments used in previous lab research (for instance, no air flow, condensation, microbe and dust deposition, nor temperature gradients), yet allows careful control of environmental factors, unlike most field studies in real buildings. Information on the study was presented at the American Industrial Hygiene Conference and Exhibition, May 22-27, in Denver, CO (Feigley et al. 2010). The system draws outside air into the laboratory system and directs half through copper heat exchangers, and half through aluminum heat exchangers. Unfiltered air outside the laboratory used for testing contains sufficient fungal and bacterial concentrations needed to demonstrate a meaningful reduction in airborne pathogens. Biological contaminants in the exit air from the copper and aluminum branches is collected on gelatin filters and is then plated, cultured, and quantified. Bacterial and fungal colony forming units detected in the exit air from both the copper and aluminum branches are analyzed to provide a side by side comparison of air quality. A more thorough description of the laboratory system has been published elsewhere (Feigley et al, 2008).

Ft. Jackson near Columbia, SC is the U.S. Army's largest site for basic training. To investigate the impact of using copper components in HVAC systems, two nearly identical barracks were selected for study. Each barracks has three floors. In one barracks all the heat exchangers and drip pans were replaced with new copper components (called the "copper barracks"), and in the other, with new aluminum components (called the "aluminum barracks"). Eight rooms on the second floor of the copper barracks were selected for sampling, and the 8 rooms in corresponding locations in the aluminum barrack were selected for sampling. Air monitoring is being performed during a 16-week heating season, and will be performed during a 16-week cooling season. Sampling is carried out 2 days per week. The total number of air samples will be 576 for each season, half from each of the modified barracks. The order of sampling was planned in advance to achieve a balanced design for statistical analysis. In order to limit sampling selection bias, as a consequence of when rooms are sampled in relation to last occupancy, the collection times are staggered between rooms.

Results Reported to Date

Laboratory research, in conjunction with the trials at the University of South Carolina and Ft. Jackson, suggests that replacing traditional HVAC components with copper equivalents has the potential to reduce biological contaminants that impact indoor air quality, increase energy efficiency, lower operational costs, and benefit human health. Incoming data from both the laboratory system at USC and the field trials at Ft. Jackson continue to generate meaningful data that will provide further insight on the quantifiable benefit of copper alloys used in HVAC systems.

CONCLUSION

Small diameter microgroove tubes allow for energy efficient designs. They allow manufacturers to use less material and less refrigerant. Small diameter Microgroove tubes allow engineers the flexibility to design for a wide variety of operating conditions. The manufacturing process that is used with small diameter MicroGroove tubes is proven, economical, robust and familiar to the entire industry. This manufacturing process is supported by a well established supply chain with manufacturing and distribution centers world-wide.

In addition to the benefits realized by copper tubes, all heat exchanger components made of copper alloys have antimicrobial properties that have the potential to improve air quality in homes and businesses. Ongoing studies funded by the U.S. Army Medical Research and Materiel Command are currently accumulating data that will provide quantifiable results that will describe in detail the extent of the benefits that are possible with copper alloy HVAC components.

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