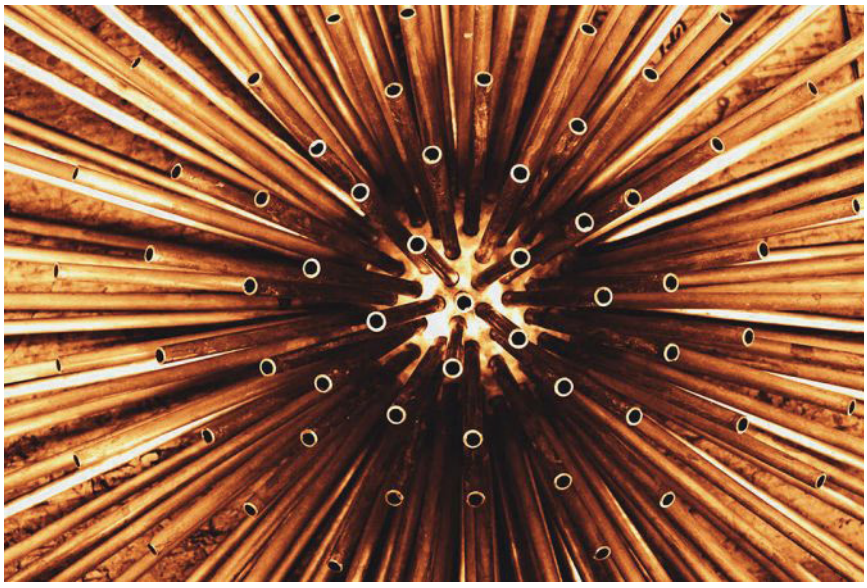


Virtual Conferences Focus on Energy Efficient Heating and Cooling

BY YORAM SHABTAY AND KERRY SONG

Advanced Technology Lowers the Demand for Energy

The energy efficiency of heating and cooling appliances and equipment steadily increased in recent years, partly thanks to the use of smaller diameter copper tubes in heat pumps, air conditioners and refrigeration systems. Efficient appliances and building systems already are helping to draw down greenhouse gas (GHG) emissions and there is still plenty of room for improvement.

Research and development on energy efficiency were presented in 2021 at ACEEE's Hot Water Forum and the Purdue's International Refrigeration and Air Conditioning Conference. Both conferences took place virtually this year and high quality presentations and papers were delivered at both.

What follows are some highlights from each of these two conferences, emphasizing the energy efficiency of heating and cooling systems.

Cheers for HPWHs at Hot Water Forum

The 13th Hot Water Forum featured more than 60 speakers presenting on a wide range of topics. Of course, participants were especially eager to learn about the use of heat pump water heaters (HPWHs) as a means to fight climate change. Grid decarbonization and electrification of homes and commercial buildings were central to many of the presentations. Emerging HPWH technologies were also discussed, including first looks at models that use low-GWP refrigerants and natural refrigerants.

Indeed, heat pumps for water and space heating represent a tremendous opportunity for "doing more with less." HPWHs allow for the electrification of water heating, and they are multiple times more efficient than electrical-resistance water heaters. High-efficiency HPWH can play a pivotal role in drawing down GHG emissions from fossil fuels.

GETTING THE WORD OUT

The Advanced Water Heating Initiative (AWHI) within the New Buildings Institute made the case for heat pump water heaters. The session titled "All Boats Rise on Heat Pump Water Heaters" included an overview of an advertising campaign that promoted HPWHs in the northwestern region of the United States. The campaign was developed in Partnership with the U.S. Department of Energy to stimulate the market for HPWHs and possibly be adopted by manufacturers and utilities nationally.

According to the AWHI Playbook and Progress Report (February 2021): https://newbuildings.org/nbi-key-markets/advanced-water-heating-initiative/

"No single region can move the national market on its own, and it will take a concerted and coordinated effort to drive HPWHs into the mainstream."

MULTIPLE MODE OPERATION

The session on "Advances in Heat Pump Water Heaters" included a presentation by Greg Pfotenhauer, who is a data scientist from Franklin Energy. Pfotenhauer described experiments on a Rheem HPWH that has three modes of operation, including Heat Pump Only, Energy Saver, and High Demand modes. Pfotenhauer examined usage data and made general recommendations for design.

LOW GWP REFRIGERANTS

In the same session, a presentation was given by researchers from Oak Ridge National Laboratory. Kashif Nawaz, Jeff Munk, Bo Shen, Ahmed Elatar and Walt Hunt delved into the consequences of using R1234yf refrigerant in a HPWH. They noted that future work would involve an optimized HPWH using a new evaporator with the system optimized for R-1234yf charge.

COPPER TUBES IN HPWHs

The session "Modeling and Optimizing Tanks, Heat Exchangers, and Controls" was of special interest to users of efficient small diameter copper tube MicroGroove technology. Yoram Shabtay from Heat Transfer Technologies and Kerry Song from International Copper Association reported on "Optimization of Copper-tube Coils for Energy Efficiency and Charge Reduction in Heat Pump Water Heaters."

Tank type water heaters are the most common water heaters and are very promising for reducing peak demand because of their large energy storage capacity. Modeling of the tank, the heat exchanger, and controls were explored in the presentation by Shabtay and Song. The slideshow is posted online at https://microgroove.net/hxsim. Qualified end-users are welcome to download a fully working copy of HXSim courtesy of ICA.

MORE MODELING FROM GTI AND ORNL

In the same session, Divya Thiagarajan and Jonathan Harrison of Gamma Technologies Inc. (GTI) introduced a physical model of buoyancy and flow phenomena within the tank itself.

The third presentation from ORNL and the Department of Energy describes a method to minimize electricity cost during time-of-use electricity pricing. Authors Kadir Amasyali, Jeffrey Munk, Kuldeep Kurte, Teja Kuruganti, and Helia Zandi detailed how controls could be used to save 11 to 33 percent in electricity costs compared to the baseline. https://www.energystar.gov/products/water_heaters/high_efficiency_electric_storage_water_heaters/how_it_works

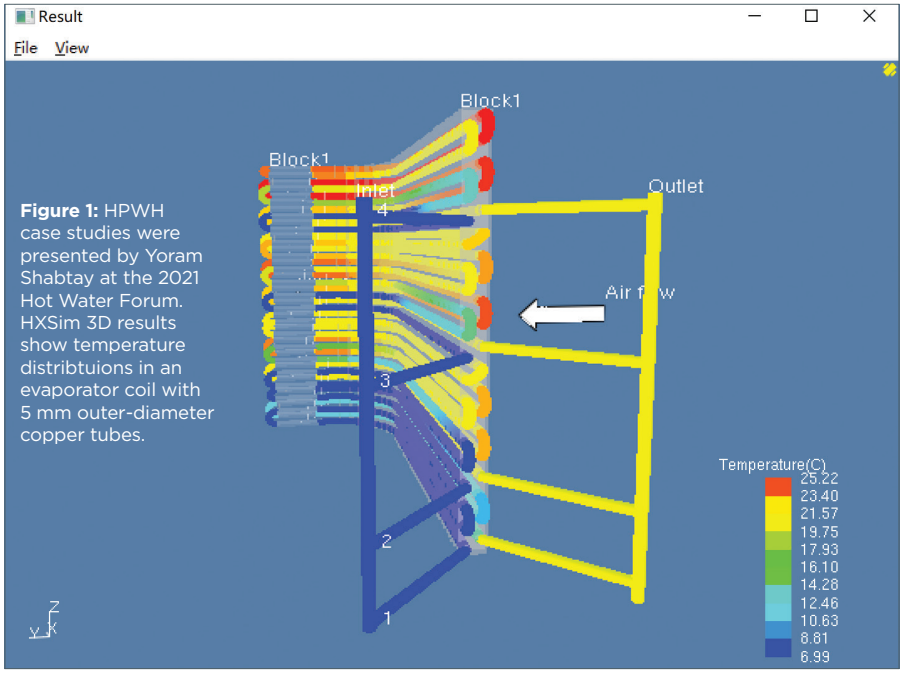


Figure 1: HPWH case studies were presented by Yoram Shabtay at the 2021 Hot Water Forum. HXSim 3D results show temperature distribtuions in an evaporator coil with 5 mm outer-diameter copper tubes.

WEEK TWO PLENARY: COMPELLING STATISTICS

The 2021 Hot Water Forum consisted of four sessions per day for four days spread over two weeks. The second week was kicked off by a plenary from the New Buildings Institute (NBI) and Advanced Hot Water Initiative (AHWI). This presentation featured excellent statistics making the case for HPWHs and fully capturing the magnitude of the mission and goals of NBI-AHWI.

NOT ONLY RESIDENTIAL

The third session on day three (i.e., session "S11") was on Next-Gen Commercial Water Heating Products. These are large WHs, including some with large evaporators split from the large hot water tank.

Ryan Hamilton of Nyle Water Heating Systems described diverse products as well as experiments with alternative and natural refrigerants in split systems, including split outdoor evaporators.

In the same session, Lynn Mueller, Matt Wardlow and Elisa Kimus from the SHARC Energy Systems demonstrated an interesting way to save energy by optimally arranging water tanks in a commercial setting. SHARC is an incubator company associated with the Electric Power Research Institute (EPRI).

Last but not least, Cain White described a 40 kW HPWH that uses carbon dioxide (R744) as a refrigerant in commercial applications. These modules can be stacked to provide hot water for large commercial applications. The helical gas cooler with copper tubes was especially noteworthy in the design. White is the director of Commercial Product Management at Mitsubishi Electric Trane HVAC US.

HPWH PRODUCT ROUNDUP

Amruta Khanolkar from the New Buildings Institute kicked off the final day of the Hot Water Forum by comparing residential HPWHs from Bradford White, Rheem, A.O. Smith, GE, Nyle, and SanCO2; and also commercial (central) HPWHs from SanCO2, Nyle, Colmac, Mitsubishi, AERMEC, Mayekawa and an unnamed US manufacturer that will release a new product in 2022.

CO2 systems from Sanden, Mitsubishi, and Mayekawa were among the commercial systems described and compared by Khanolkar.

All told, the 2021 Hot Water Forum exceeded expectations. The importance of this forum is underscored by the fact that water heating ranks third in terms of energy usage for domestic applications, exceeded only by space heating and space cooling.

A Virtual Gathering at Purdue 202ONE

The organizers of the Purdue Conferences were forced to postpone the biannual conference that normally would have occurred in July 2020; although there were aspirations to meet live in 2021, a decision was made to go "virtual only" for the rescheduled event, which was dubbed "202One."

DESTINATION GATHER TOWN

The chosen "virtual setting" (i.e., "Gather" or "Gather Town") was well suited for Purdue 202One. Papers and presentations could be viewed in advance and participants used an avatar to virtually "walk the floor" of Gather Town, striking up live video chats with authors and other attendees. Upon entering a virtual conference room in Gather Town, one could readily view the featured slideshow and paper and spontaneously interact with the original investigators as well as the assembled group.

The range of topics was quite extensive. Of possible interest to heat-exchanger engineers and appliance designers are papers on the following topics.

- Tube and fin research
- Coil circuitry (including distributor design)
- Refrigerants
- Appliance design

There were several papers about the properties of tubes, including copper tubes, and in some cases specifically on MicroGroove smaller-diameter copper tube technology.

NOTE: Purdue 202One papers can be accessed online from this webpage. https://docs.lib.purdue.edu/iracc/ Search 2021 papers using paper number, author(s), company or the title of the paper.

A PRIZE WINNING TECHNIQUE

Min Che and Stefan Elbel from the University of Illinois Urbana presented on "Experimental Evaluation of Local Air-Side Heat Transfer Coefficient on Single Fins" (Paper 2176). The paper won first place for doctoral candidate Min Che in the student competition. https://mechse.illinois.edu/news/40254.

Che described new experimental methods for visualizing and quantifying Heat Transfer Coefficient (HTC) distributions on fin surfaces. The technique involves spraying a thin yellow coating (20 μm) on the fins and placing them in a wind tunnel. Tracer quantities of ammonia are present in the wind tunnel airflow, causing the color of the surface of the fins to change from yellow to blue. By correlating the rate of local color change with the rate of local mass transfer (and hence also heat transfer) local HTCs on the fin surfaces can be quantified.

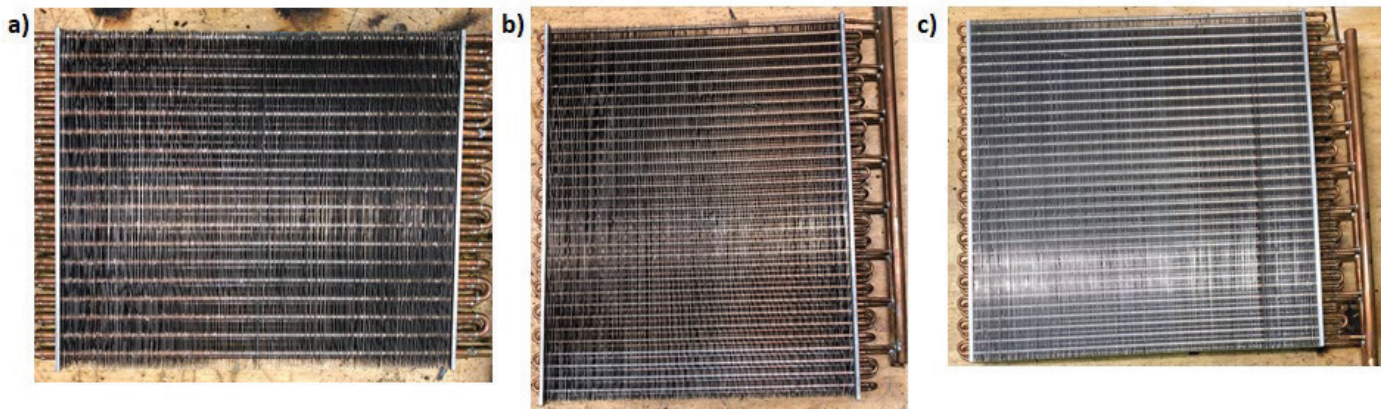


Figure 2: Simulation results for MicroGroove copper tubes were verified by wind tunnel tests on actual heat exchangers: ***(a)*** coil with 5 mm tubes and 19 fins per inch (fpi); ***(b)*** 3 mm tubes and 21 fpi; ***(c)*** 3 mm tubes and 28 fpi.

FIRST 3 mm DIAMETER COPPER TUBE HEAT EXCHANGER

The paper on "Design Optimization of 3 mm and 5 mm Copper Tube and Flat Fin Air-to-Water Heat Exchangers with Experimental Validation" (Paper 2195) is of particular interest to followers of MicroGroove Technology.

Authors included Daniel Bacellar, Dennis Nasuta, Song Li and Cara Martin from Optimized Thermal Systems, Inc. Beltsville, Maryland as well as Dale Powell of the Copper Development Association. The simulation results were validated by building prototype heat exchangers.

According to the authors, to the best of their knowledge, the experimental work is the first that performed experimental tests on a heat exchanger using 3 mm diameter copper tubes. The numerical optimization illustrated how, under equivalent geometry characteristics, a 3 mm diameter tube offers advantages with respect to thermal-hydraulic performance.

LABORATORY VALIDATION OF FIN-AND-TUBE HEAT EXCHANGER SIMULATIONS

Researchers claim they can validate computer simulations to a high degree of accuracy, using a novel experimental apparatus that includes a small wind tunnel.

Results were presented in a paper titled "Development of Novel Experimental Infrastructure for Collection of High-Fidelity Experimental Data of Refrigerant to Air Heat Exchangers" (Paper 2222). The paper was authored by Saad Saleem, Craig R. Bradshaw and Christian K. Bach from Oklahoma State University; and Omer Sarfraz from Johnson Controls.

The data collection apparatus collects high fidelity experimental data for fin-and-tube heat exchangers for three operating modes: (1) single-phase refrigerant, (2) evaporator, and (3) condenser mode. The pumped refrigerant loop can control refrigerant test conditions as well as the flowrate to each individual heat exchanger circuit. The apparatus has been sized to test heat exchanger coils up to a capacity of 5 tons (17.5 kW).

The first test of the apparatus was carried out on a typical copper tube coil with aluminum fins. This four circuit coil could also be simulated with HXSim simulation software from the International Copper Association.

NOVEL TUBE SHAPES

A memorable technical article on novel tube shapes is titled "Experimental Study of a Novel Shape-Optimized Air-to-Refrigerant Heat Exchanger under Evaporator Conditions" (Paper 2539). The paper was authored by Ellery Klein, Vikrant Aute and others from University of Maryland and Yoram Shabtay from Heat Transfer Technologies.

Using the novel tube shape, a finless heat exchanger was designed with a 25 percent reduction in volume, 20 percent reduction in face area, and an 8 percent reduction of internal volume compared to a state-of-the-art, air-to-refrigerant heat exchanger; yet it was designed to have the same air-side pressure drop and a capacity equal to or greater than the conventional heat exchanger. The predicted and measured values show good agreement, with the performance verified under dry and wet evaporator conditions using R 410A as the refrigerant.

AUGMENTING NUCLEATION ON COPPER TUBES

Numerous researchers have found that surface roughness can enhance pool boiling heat transfer. Most recently magnetic abrasive finishing (MAF) was used to augment the activated nucleation sites on the internal surfaces of copper tubes. The technique provided higher heat transfer coefficients for the in-tube flow boiling as expected.

"Heat Transfer and Pressure Drop Characteristics of Water Flow Boiling in Internally Enhanced Tubes" (Paper 2685) delivers the results from three laboratories. Three authors from Oak Ridge National Laboratory (Cheng-Min Yang, Kashif Nawaz, and Anthony Gehl) collaborated with two from the University of Florida, Gainesville (Hitomi Yamaguchi and Fang Xu) and one from Texas A&M University (Jorge Alvarado) to develop and test a copper tube internally enhanced using the MAF technique.

BALANCING RTPF WITH MCHX

Moving beyond studies focused on tubes, several papers addressed tube circuitry and maldistribution.

As an indicator of the continued importance of such research, Khaled Ibrahim Alghamadi and Christian Konrad Bach from Oklahoma State University endeavored to balance a system that uses microchannel tubes in the condenser and 10 mm round tubes in the evaporator. Their results are given in a paper titled "Dynamic Modeling of Packaged Air Conditioner with Microchannel Heat Exchanger Condenser" (Paper 2267).

The reasons for using round tubes in the evaporator have to do with the maldistribution of refrigerant that can occur with microchannel heat exchangers. After reviewing the literature on modeling the system balancing, the authors point out that little work has been done on systems that include a combination of microchannel tubes and round tubes.

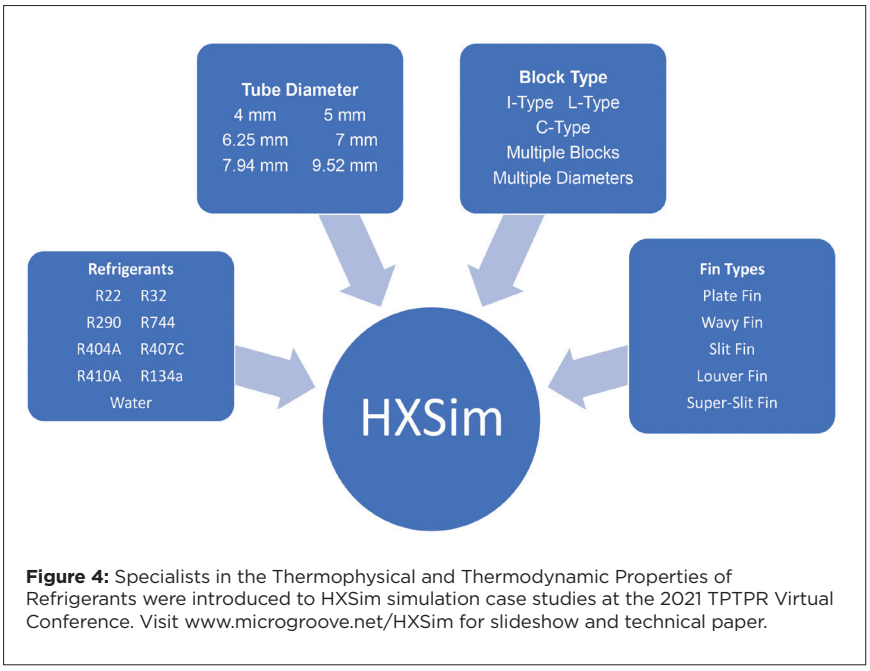


Figure 4: Specialists in the Thermophysical and Thermodynamic Properties of Refrigerants were introduced to HXSim simulation case studies at the 2021 TPTPR Virtual Conference. Visit www.microgroove.net/HXSim for slideshow and technical paper.

OPTIMIZING THE DISTRIBUTORS

Although the details of the research are beyond the scope of this overview, several papers on flow distribution are noteworthy.

Yufang Yao and Pega Hrnjak, from University of Illinois and Creative Thermal Solutions, respectively, presented a two-part paper on refrigerant distributors (Paper 2464). Part one (10 pages) is titled "Effect of flow regime before distributor on two-phase flow distribution" and part two (9 pages) is titled "Effect of orientation on performance of the refrigerant distributor."

Their research demonstrates the effect of the flow regime at the distributor inlet on the uniformity of two-phase flow distribution. The flow regime is determined by mass flux, quality, and distance from the expansion device. A high-speed camera is used to visualize the two-phase flow regimes between the expansion valve and distributor; and also to interrogate the flow regime inside the distributor. A close study of both of these papers provides insights into the design of distributors and circuitry for evaporators.

Similarly, Saugata Sarkar, who is a senior thermal system engineer with Triumph Group Integrated Systems, provides insights into evaporator designs through modeling of ideal distributors in a paper titled "Computational Fluid Dynamics (CFD) Modeling of Two Phase Refrigerant Flow in Evaporator Distribution System" (Paper Search Term: Triumph).

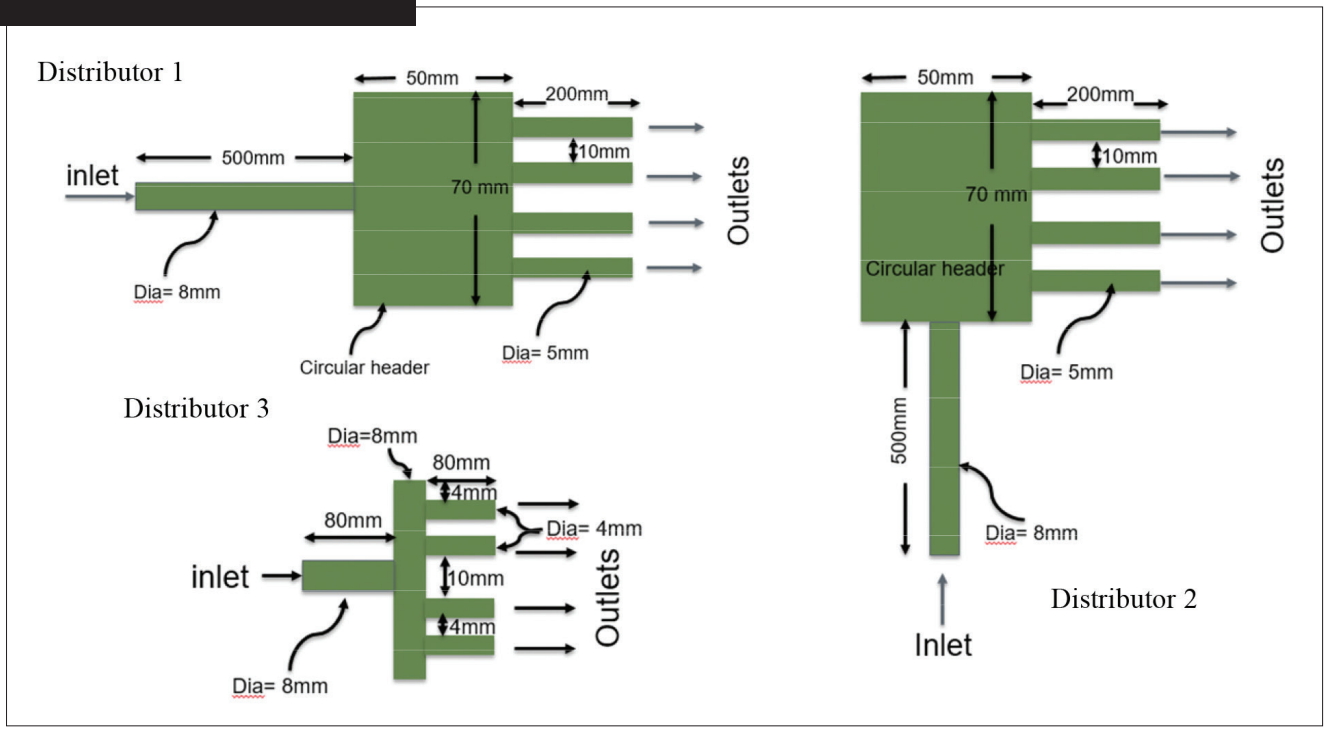


Figure 3: The performances of these three ideal distributors were simulated by Saugata Sarkar, a senior thermal system engineer with the Triumph Group. (Illustration used with permission.)

The more general topic of how to simulate distributors was tackled by Zhenning Li from ORNL and Vikrant Aute from University of Maryland. They outlined their algorithm for the optimization of circuitry in evaporators in a paper titled "Enhanced Integer Permutation based Genetic Algorithm for Optimization of Tube-Fin Heat Exchanger Circuitry with Splits and Merges" (Paper 2574). According to their case studies, optimal designs obtained using their algorithm exhibit higher capacity, lower pressure drop and better manufacturability compared to baseline designs.

RESEARCH ON REFRIGERANTS

Refrigerant blends are on the minds of heat exchanger designers everywhere as OEMs strive to reduce the GWP of refrigerants in AC, heat pump and refrigeration applications. The use of blends allows designers to make tradeoffs between GWP, flammability, cost and performance.

Ternary blends obtained mixing hydrofluorocarbons (HFC) and hydrofluoroolefins (HFO) have recently been proposed as substitutes for high global warming potential (GWP) fluids employed in refrigeration and air-conditioning. Several papers from the Purdue Conference give a preview of what is to come.

Ternary blends were also a hot topic on the program of the Thermophysical Properties and Transfer Processes of Refrigerants (TPTPR), an international conference that takes place every four years. This year TPTPR was a virtual event from September 1-3, 2021. A paper on heat-exchanger simulations was presented at TPTPR 2021 by Yoram Shabtay, Kerry Song and Frank Gao of HTT and ICA. The TPTPR presentation and the paper titled "Simulation of the effects of copper tube diameter on refrigerant charge reduction in split AC systems and refrigerated cabinets" are available online at https://microgroove.net/hxsim.

PADOVANS LOOK AT R455A AND R452B

The University of Padova is renowned for its work on the thermophysical properties of refrigerants. Marco Azzolin, Arianna Berto, Stefano Bortolin and Davide del Col recently conducted research on two different zeotropic ternary mixtures: R455A, which is a mixture of R32, R1234yf and R744 (21.5/75.5/3.0% by mass composition); and R452B, which is mixture of R32, R1234yf and R125 (67.0/26.0/7.0% by mass composition).

They measured condensation and flow boiling heat transfer coefficients inside a minichannel (0.96 mm diameter) and inside a conventional tube (8.0 mm diameter) for these blends. The results of these methodical laboratory measurements were reported in a paper titled "Two-Phase Heat-Transfer of Low GWP Ternary Mixtures" (Paper 210049).

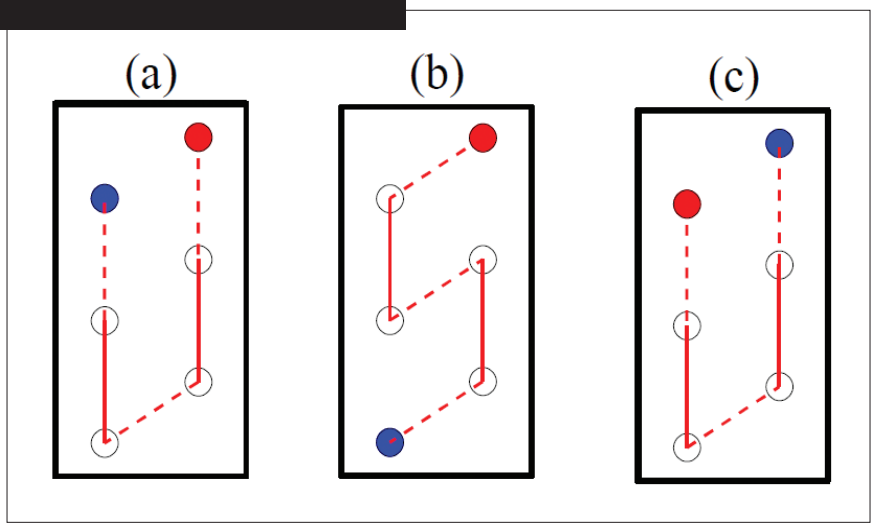
ORNL DOUBLES DOWN ON REFRIGERANT BLENDS

Researchers from Oak Ridge National Laboratories (ORNL) described a novel framework for optimizing low-GWP refrigerant mixture compositions. Using this framework, new refrigerants can be matched to the system. The condenser and evaporator circuitry configurations can be optimized simultaneously with the mixture compositions.

The case studies using an experimentally validated R410A Roof Top Unit (RTU) show that the proposed optimization approach can generate new binary and ternary mixtures and new circuitry designs to improve system EER, reduce refrigerant flammability, and maintain a low GWP.

This paper is titled "Optimization of Refrigerant Compositions for Low-GWP Refrigerant Mixtures Using Segment-by-segment Heat Exchanger and Detailed System Models" (Paper 2614). The ORNL authors are Zhenning Li, Bo Shen, and Kyle Gluesenkamp.

Figure 5: Shen and Li from ORNL describe these three basic types of tube circuitry a paper about low-GWP refrigerants. (Illustration used with permission.)



EMERSON WEIGHS IN ON LOW-GWP OPTIONS

The new refrigerant blends and the optimized heat exchangers must work in harmony with the compressors. Emerson weighed in on new refrigerant mixtures with a paper titled "HVAC Systems with Low Global Warming Potential Refrigerants: A Case Study" (Paper 2144) by Vijay Bahel, Rajan Rajendran, Brian Butler and Drew Welch, from Emerson, Dayton, Ohio.

The Emerson paper provides an excellent overview of things to come with respect to refrigerant blends. In the conclusion, the authors state key takeaways as follows: (1) we can conclude that R-32 and R-454B, two popular R-410A replacement candidates with a GWP below 750, both have system performance equal to or better than R-410A; (2) refrigerant options with a GWP below 300 all underperform versus R-410A. The authors also found electronically commutated motors (ECM) to be more efficient than permanently split capacitor (PSC) condenser fans and evaporator blower motors.

EFFECTS OF MICROFINS ON BLENDS

Ethan P. Matty and Brian M. Fronk from Oregon State University compared the condensation heat transfer and pressure drop for zeotropic refrigerant R454C and its individual components in a horizontal microfin tube with a 4 mm outer diameter. According to these authors, microfin tubes enhance heat transfer by several mechanisms: the microfins increase the internal surface area of the tube, the fins drain condensate from the fin tip to the trough region, and the microfins produce secondary flow structures.

Noting the limited data on HFO/HFC mixtures in microfin tubes, Matty and Fronk conducted experiments on the complete condensation of R454C, R1234yf and R32 for saturation temperatures of 40, 50 and 60 °C and mass fluxes from 100 to 600 kg/m^{2}s. They compared their results on heat transfer and pressure drop to correlations from the literature; and they also calculated heat transfer enhancement factors and pressure drop penalty factors for each refrigerant. Their paper is titled "A Comparison of Condensation Heat Transfer and Pressure Drop for Zeotropic Mixture R454C and its Components, R32 and R1234yf, in a Horizontal Microfin Tube." (Paper 210068)

THE MULTIPLE BENEFITS OF LESS CHARGE

No matter the HFC/HFO blend, lowering the refrigerant charge has the dual effect of reducing the system GWP and also the amount of flammable refrigerant in the system. Costantino Guzzari, Marco Azzolin, Sandro Lazzarato and Davide del Col from the Università degli Studi di Padova addressed this issue in the paper titled "Effect of the refrigerant charge on the system performance and mass distribution in air-to-water systems" (Paper 210064).

These authors analyzed the influence of refrigerant charge on the system performance and on the mass distribution in an air-to-water reversible heat pump working with R32. They used a mathematical model to predict the refrigerant charge within the heat exchangers. The results show that most of the charge is stored in the condenser and that an optimal charge can be found to maximize the system COP. The same model can be used to compare various refrigerants in terms of direct and indirect impact on the greenhouse effect.

CONCEPTS IN APPLIANCE DESIGN

Many of the results mentioned above directly apply to the development of optimized heat exchangers for improving the efficiency of appliances, including heat pumps for space heating and water heating; as well as air conditioners and refrigeration equipment. There were also papers specifically on heat pumps for clothes dryers and dishwashers.

Examples of papers on clothes dryers include a paper titled "Experimental Investigation of a Heat Pump Tumble Dryer with a Zeotropic Refrigerant Blend" (Paper 1012) from the Technische Universität Dresden; and a paper titled "Thermodynamic Analysis of Thermo-vacuum Clothes Drying Operation" (Paper 2406). The latter paper is a collaboration between Wilson Engineering Technologies, Inc., the Gas Technology Institute (GTI), and ORNL. It examines the intriguing concept of drying clothes in a vacuum in which case the speed of drying could be increased and the energy consumption decreased by the vacuum.

A dedicated heat pump for producing very high temperature water for a commercial dishwasher is described in a paper titled "Development of a High Temperature Water Heat Pump in Vent-Less Dishwasher Application" (Paper 2341) by Daqing Li and Suresh Shivashankar, who are both from Emerson Commercial & Residential Solutions, in Sidney, Ohio, USA.

This brief synopsis paints a picture of ongoing research from national laboratories, universities, industry suppliers and OEMs. As fundamental research advances, it is clear that there is much room for improvements in the efficiency of heating and cooling appliances and equipment.

Scientific research on the refrigeration cycle, the thermophysical properties of refrigerants and the optimization of heat exchanger designs gives appliance designers new tools and technologies for efficient heating and cooling in residential, commercial and industrial applications.

Countdown to 2021 UN Climate Change Conference

As we look ahead to COP26, an important question looms: What can be done to further improve the energy efficiency of heating and cooling systems?

The 2021 UN Climate Change Conference (COP 26) is scheduled to take place in the city of Glasgow, Scotland from October 31 to November 12, 2021.

Although the conference was delayed by the global pandemic for one year, expectations are high as world leaders, policy makers and scientists gather for what promises to be a turning point in addressing climate change.

Aggressive-yet-realistic targets for the reduction of greenhouse gas (GHG) emissions will be deliberated in Glasgow. Progress has been made since the Paris Agreement was negotiated at COP 21 in 2015 but much more progress is needed to avert climate catastrophes in our lifetime.

Energy production by solar and wind has increased significantly in the past 20 years. In many instances, it is now less costly to generate electricity from solar and wind rather than fossil fuels. The technology exists.

What is still lacking is the willingness to put the technology into action and scale up clean technologies by a few orders of magnitude if we are to be successful in scaling down reliance on fossil fuels.

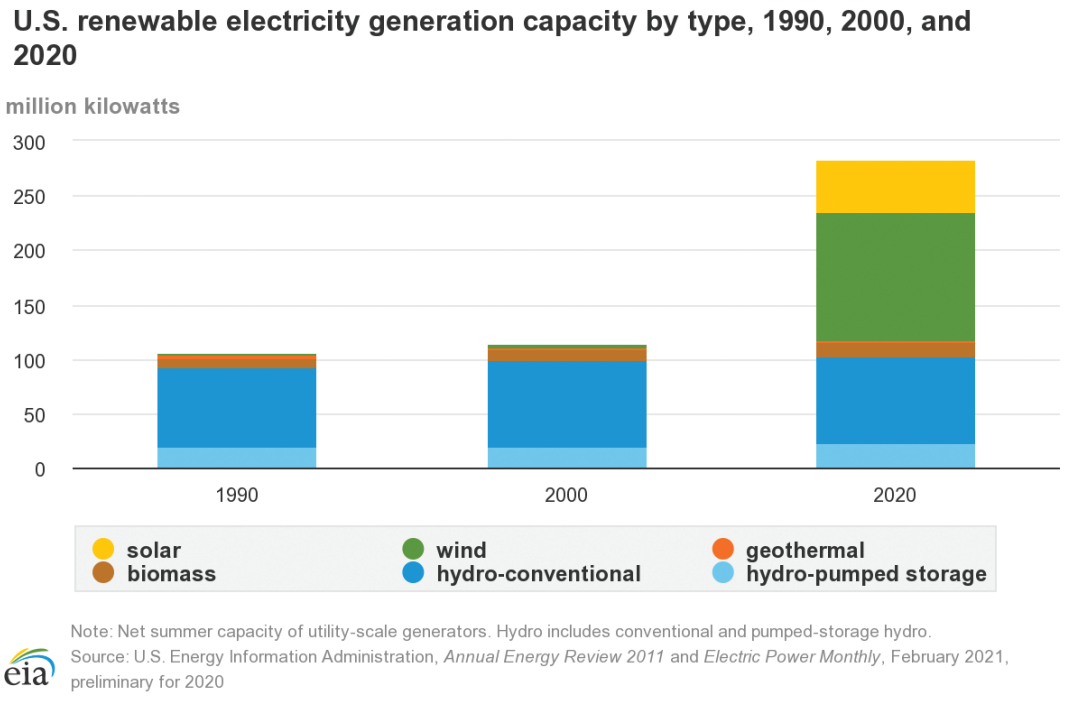
Drawing down usage of fossil fuels such as coal, oil and gas is the key to reaching sustainability goals of the Paris Climate Treaty. Renewable energy resources such as wind and solar can replace coal-burning power plants. Simultaneously, in transportation and buildings, the use of oil and gas can be drawn down through the electrification of automobiles and heating systems.

This transition will be facilitated by the use of smaller-diameter copper tubes in high-efficiency heat exchangers, which allow for the development of systems that consume less energy. ●

***Yoram Shabtay**, President of Heat Transfer Technologies, has extensive background in heat exchangers development and production and has been working with the ICA for over two decades.*

***Kerry Song** is a Project Manager with the International Copper Association. He is also the Secretary-General of Refrigeration and Air-conditioning Heat Exchanger Technology Alliance in China.*

Figure 6: All eyes will be on Glasgow this Fall for the UNCCC (COP 26).



Note: Net summer capacity of utility-scale generators. Hydro includes conventional and pumped-storage hydro.
Source: U.S. Energy Information Administration, *Annual Energy Review 2011* and *Electric Power Monthly*, February 2021, preliminary for 2020