

# CONTENTS

Host Chapter, Officers, and Conferences and Expositions Committee .....	xiv
State of Society Address, Darryl K. Boyce, 2019–2020 ASHRAE President .....	xv
Technical Program .....	xviii

## CONFERENCE PAPERS

<b>OR-20-C001</b>	A Case Study of Using Multi-Functional Sensors to Predict the Indoor Air Temperature in Classrooms Ehsan Kamel, PhD, Member ASHRAE; Amir Javan-Khoshkholgh, PhD; Nadi Abumahfouz; Siqi Huang; Xueqing Huang, PhD; Aydin Farajidavar, PhD; Yumin Qiu .....	3
<b>OR-20-C002</b>	Demand Control of Baseboard Heaters Using Connected Thermostats: Lessons Learned from a 567-Home Pilot Study Ajit Pardasani; Jennifer A. Veitch, PhD; Yitian (Vera) Hu; Guy R. Newsham, PhD .....	12
<b>OR-20-C003</b>	Smart Control for Optimum Residential Fuel Switching between Natural-Gas and Electricity Farzin M. Rad, PhD, PEng, Member ASHRAE; Nima Alibabaei, PhD; Tom Grochmal, PhD, PEng .....	21
<b>OR-20-C004</b>	Project SHOES: Secondary Heat Opportunities from Electrical Substations James Bowman; Akos Revesz, PhD; Gareth Davies, PhD; Graeme Maidment, PhD, CEng .....	29
<b>OR-20-C005</b>	Preliminary Study of a Solar Assisted Heating System Gareth Davies, PhD; John Blower; Richard Hall; Graeme Maidment, PhD, PE .....	39
<b>OR-20-C006</b>	A New Look at Elevator Pressurization John H. Klote, PE, Fellow ASHRAE; Paul G. Turnhull, Member ASHRAE .....	48
<b>OR-20-C007</b>	The Impact of Sweeps and Weather Stripping on Suite Door Air Tightness Xinxu Tian, Student Member ASHRAE; Jamie Fine, PhD, Associate Member ASHRAE; Marianne Touchie, PhD, Associate Member ASHRAE .....	56
<b>OR-20-C008</b>	Ventilation and Indoor Environmental Quality Perceptions in Post-War MURBs Jamie P. Fine, PhD, Associate Member ASHRAE; Marianne F. Touchie, PhD, PEng, Associate Member ASHRAE .....	65
<b>OR-20-C009</b>	Indoor Environmental Quality Evaluation of an Institutional Building Lexuan Zhong, PhD, PEng, Member ASHRAE .....	74
<b>OR-20-C010</b>	Indoor Heat Stress Index Based on the Predicted Heat Strain Model and its Application Yue Zou, PhD, Member ASHRAE; Yang Li .....	82
<b>OR-20-C011</b>	Spatial Uniformity of Thermal Comfort from Ceiling Fans Blowing Upwards Thomas Parkinson, PhD, Member ASHRAE; Paul Raftery, PhD, Member ASHRAE; Elaina Present, Student Member ASHRAE .....	91
<b>OR-20-C012</b>	Investigating the impacts of Solar Screens on Occupant's Thermal Comfort: An Observational Field Study Niyati Naik, Student Member ASHRAE; Ihab Elzeyadi, PhD .....	99
<b>OR-20-C013</b>	Investigating the Impact of Plant Phytoremediation on Indoor Air Quality in Work Environments: A Meta-Analysis Hooman Parhizkar, Student Member ASHRAE; Ihab Elzeyadi, PhD, Member ASHRAE .....	109

<b>OR-20-C014</b>	Modelling of Thermally Active Walls for Building Energy Reduction Brandon S. Field, PhD; Michael Sandefur.....	120
<b>OR-20-C015</b>	Gradient Descent for Multi-Objective Optimization to Find a Cohesive Solution for Fenestration Sizes Sara Motamedi, PhD .....	128
<b>OR-20-C016</b>	Cost-Optimal Sizing and Operation of a Hybrid Heat Pump System Using Numerical Simulation Noah Rauschkolb, Student Member ASHRAE; Vijay Modi, PhD; Patricia Culligan, PhD .....	134
<b>OR-20-C017</b>	A New Model for Two-Phase Flow Boiling Heat Transfer of Refrigerant and Nanolubricant Mixtures in Smooth Tubes Pratik S. Deokar, Student Member ASHRAE; Lorenzo Cremaschi, PhD, Member ASHRAE; Andrea A.M. Bigi, PhD, Member ASHRAE.....	144
<b>OR-20-C018</b>	125 Years of ASHRAE: What I Have Learned in the Last 35 Years Regarding Refrigerants and Lubricants Chemistry and Interactions Joseph Karnaz, Member ASHRAE.....	154
<b>OR-20-C019</b>	Development of Multi-Stage Two-Evaporator Transcritical Carbon Dioxide Cycle for Experimental Comparisons of Expansion Work Recovery Technologies Riley B. Barta, Student Member ASHRAE; Davide Ziviani, PhD, Member ASHRAE; Eckhard A. Groll, Dr. Ing., Fellow ASHRAE .....	162
<b>OR-20-C020</b>	Numerical Enhancement Analyses of Refrigerator Vortex Tubes Cooling Performance Mahmoud Abdelghfar; Karam R. Beshay; Gamal Elhariry; Essam E. Khalil, Fellow ASHRAE .....	172
<b>OR-20-C021</b>	Assessing the Performance of District Heating Networks Utilising Waste Heat: A Review Henrique Lagoeiro; Akos Revesz, PhD; Gareth Davies, PhD; Daniel Curry; Gareth Faulks; Michal Murawa; Graeme Maidment, PhD, PE.....	180
<b>OR-20-C022</b>	Survey of an Exhaust Ventilation System in Combination with a Drain Water Heat Recovery for Social Housing Elisabeth Wieder, Michael Bayer, Thomas Reiter, Markus Leeb .....	189
<b>OR-20-C023</b>	Experimental and Numerical Investigation on a Polymer Heat Exchanger for Pouch-Type Battery Thermal Management System Ukmin Han, Student Member ASHRAE; Hoseong Lee, PhD.....	196
<b>OR-20-C024</b>	Absorption Cooling for Data Centers Powered by Solid Oxide Fuel Cell Waste Heat Alejandro Lavernia; Maryam Asghari; Jack Brouwer, PhD.....	204
<b>OR-20-C025</b>	Study on a Cooling System with Power Usage Effectiveness of 1.02x for Server Rooms Naoki Aizawa, Member ASHRAE.....	212
<b>OR-20-C026</b>	CFD Application to Improve Infection Control in Office Rooms Ahmed EIDegwy; Mohammed Sobhi; Essam E. Khalil, Fellow ASHRAE .....	220
<b>OR-20-C027</b>	Experimentally Validated CFD Analysis on the Optimal Sensor Location for the CO <sub>2</sub> -Based Demand-Controlled Ventilation Gen Pei, Student Member ASHRAE; Donghyun Rim, PhD, Associate Member ASHRAE .....	229
<b>OR-20-C028</b>	The Effect of Boundary Conditions on Transient Airflow Patterns: A Numerical Investigation of Door Operation Arup Bhattacharya, Student Member ASHRAE; Ehsan Mousavi, PhD, Associate Member ASHRAE .....	239

<b>OR-20-C029</b>	Design Optimization for Dairy Barns Using Computational Fluid Dynamics Thomas M. Thibault, Affiliate Member ASHRAE; Bernardo J. Majano, PEng; Natasha M. Lee, PEng; Murray P. Amirault, PEng; Donnie Anderson .....	247
<b>OR-20-C030</b>	Wi-Fi Based Occupancy Clustering and Motif Identification: A Case Study Brodie W. Hobson, Student Member ASHRAE; H. Burak Gunay, PhD, Associate Member ASHRAE; Araz Ashouri, PhD; Guy R. Newsham, PhD .....	256
<b>OR-20-C031</b>	Occupancy Sensing in Buildings through Social Media from Semantic Analysis Xing Lu, Student Member ASHRAE; Fan Feng, Student Member ASHRAE; Zheng O'Neill, PhD, PE, Member ASHRAE .....	265
<b>OR-20-C032</b>	Nationwide Energy Saving Potential Evaluation for Office Buildings with Occupant-Based Building Controls Zhihong Pang, Student Member ASHRAE; Yan Chen, Member ASHRAE; Jian Zhang, Member ASHRAE; Zheng O'Neill, Member ASHRAE; Hwakong Cheng, Member ASHRAE; Bing Dong, Member ASHRAE .....	273
<b>OR-20-C033</b>	Visual Environmental Parameters Associated with Visual Satisfaction in Multiple Office Buildings Young Joo Son, Student Member ASHRAE; Vivian Loftness; Linhao Li; Azizan Aziz .....	282
<b>OR-20-C034</b>	A Novel Simulation Framework for Comfort-based Assessments of Window Designs Shengbo Zhang; Jamie Fine, PhD, Associate Member ASHRAE; Marianne F. Touchie, PhD, Associate Member ASHRAE; William O'Brien, PhD, Associate Member ASHRAE .....	289
<b>OR-20-C035</b>	Raising the Bar: Comparing Building Energy Benchmarking Methods Jamie Kono, PE, Affiliate Member ASHRAE; Meghan K. McNulty, PE, Member ASHRAE; Barry Abramson, PE, Member ASHRAE .....	300
<b>OR-20-C036</b>	Codes for Loads: Bringing Energy Codes into the 21st Century with Time-of-Use Efficiency Jim Edelson, Member ASHRAE; Alexi Miller, PE, Member ASHRAE; Kevin Carbonnier, PhD ...	308
<b>OR-20-C037</b>	Right-Sizing Electric Heat Pump and Auxiliary Heating for Residential Heating Systems Based on Actual Performance Associated with Climate Zone Alejandro Baez Guada, Member ASHRAE; Tim Kingston, Member ASHRAE; Paul Glanville, Member ASHRAE.....	316
<b>OR-20-C038</b>	Integrated Gas-fired Heat Pump Water Heaters for Homes: Results of Field Demonstrations and System Modeling Paul Glanville, PE, Associate Member ASHRAE; Alex Fridlyand, PhD, Associate Member ASHRAE; Michael Mensinger, Jr.; Merry Sweeney; Chris Keinath, PhD, Associate Member ASHRAE .....	325
<b>OR-20-C039</b>	Space Heating Boiler System Performance in Post-War High-Rise Multi-Family Buildings Helen Stopps, Student Member ASHRAE; Marianne Touchie, PhD, PEng, Associate Member ASHRAE .....	333
<b>OR-20-C040</b>	Optimizing Condenser Water Supply Temperature to Minimize Energy Usage Andrew Chin; Robert Faddoul; Cristian Lacey; Andrew Mosin; Oliver Zhang; Melody Baglione, PhD; John Rundell, PE .....	342
<b>OR-20-C041</b>	Analytical Model for a 10 Cylinder Swash Plate Electric Compressor M. Arqam, D.V. Dao, A. Jahangiri, H. Yan, M. Mitchell, P.L. Woodfield .....	351

<b>OR-20-C042</b>	Analysis of Wind Speed Influence on Heat Recovery Efficiency of Local Decentralized Alternating Ventilation Units Jurgis Zemitis, PhD; Anatolijs Borodinecs, PhD, Member ASHRAE.....	360
<b>OR-20-C043</b>	Arrange Your Air-Handling Unit Components Wisely Stephen W. Duda, PE, HFDP, HBDP, BEAP, Fellow ASHRAE.....	369
<b>OR-20-C044</b>	Experimental Study on Particle Depositions for Different Ventilations During Vacuuming Walid Chakroun, PhD, Fellow ASHRAE; Sorour Alotaibi, PhD, Member ASHRAE; Kamel Ghali, PhD, Member ASHRAE; Nesreen Ghaddar, PhD, Member ASHRAE.....	378
<b>OR-20-C045</b>	A Case Study for District Cooling Plant with Different Green Resources Scenarios to Reach an Optimized Energy Model Mohamed F. Heider, Member ASHRAE; Hesham Safwat, Member ASHRAE; Ahmed El-Baz.....	386
<b>OR-20-C046</b>	WITHDRAWN	
<b>OR-20-C047</b>	New Buildings Should Never Operate Cooling Towers and Boilers Simultaneously Richard E. Franseen, PE, Member ASHRAE.....	395
<b>OR-20-C048</b>	WITHDRAWN	
<b>OR-20-C049</b>	Applying Machine Learning Based Data-Driven Approach in Commercial Building Energy Prediction Xi Cheng, PE, HBDP, Associate Member ASHRAE .....	403
<b>OR-20-C050</b>	A Cybersecurity Framework for Wireless-Controlled Smart Buildings I: Two-Position Control Feng Wu, Student Member ASHRAE; Ming Qu, PhD, Member ASHRAE .....	412
<b>OR-20-C051</b>	RL-HEMS: Reinforcement Learning Based Home Energy Management System for HVAC Energy Optimization Olivera Kotevska, PhD; Kuldeep Kurte, PhD; Jeffrey Munk, PhD; Travis Johnston, PhD; Evan McKee; Kalyan Perumalla, PhD; Helia Zandi.....	421
<b>OR-20-C052</b>	Ensemble Method for Short-Term Load Forecasting Using LSTM, SVR, and FFNN Taking into Account Seasonal Dependency Vishnu Prakash, Student Member ASHRAE; Hannah Fontenot, Student Member ASHRAE; Asad Ali Khan; Bing Dong, PhD, Associate Member ASHRAE; Miltiadis Alamaniotis, PhD .....	430
<b>OR-20-C053</b>	WITHDRAWN	
<b>OR-20-C054</b>	WITHDRAWN	
<b>OR-20-C055</b>	Mass Balance Analysis of Air Change Rate (ACR) and Space Volume on Contaminant Dilution Kishor Khankari, PhD, Fellow ASHRAE .....	439
<b>OR-20-C056</b>	WITHDRAWN	
<b>OR-20-C057</b>	Restroom Ventilation Schemes: Energy Implications Travis R. English, PE, Member ASHRAE.....	448
<b>OR-20-C058</b>	Investigation of Quantitative Relationships between Occupant Satisfaction and Household IAQ-Related Characteristics in California Homes Yang-Seon Kim, PhD, Member ASHRAE; Brett C. Singer, PhD, Member ASHRAE; W. Rengie Chan, PhD; Iain S. Walker, PhD, Fellow ASHRAE.....	456

<b>OR-20-C059</b>	Investigating How Occupancy and Ventilation Mode Influence the Dynamics of Indoor Air Pollutants in an Office Environment Jinglin Jiang, Student Member ASHRAE; Tianren Wu, Student Member ASHRAE; Danielle N. Wagner, Student Member ASHRAE; Philip S. Stevens, PhD; Heinz J. Huber, PhD; Antonios Tasoglou, PhD; Brandon E. Boor, PhD, Associate Member ASHRAE .....	464
<b>OR-20-C060</b>	Energy, Environmental, Economic Evaluation of Residential Building with Micro-CHP in South Korea Yujun Jung, Student Member ASHRAE; Hoseong Lee, PhD .....	474
<b>OR-20-C061</b>	Performance Assessment of Hybrid (Gas Furnace + Heat Pump) Systems with Smart Switching Controls Jeremy Sager, Alexandre Bouchard, Sewar Haj-Nabou .....	482
<b>OR-20-C062</b>	Initial Assessment of a 5th Generation District Energy Network in Central London Akos Revesz, Catarina Marques, Gareth Davies, Rodrigo Matabuena, Phil Jones, Chris Dunham, Graeme Maidment .....	491
<b>OR-20-C063</b>	Dynamic Modelling and Performance Evaluation of a Chemisorption Heat Pump for Cold Climate Zhiyao Yang, Student Member ASHRAE; Ming Qu, PhD, Member ASHRAE; Kyle R. Gluesenkamp, PhD, Member ASHRAE .....	500
<b>OR-20-C064</b>	Optimization of Design Solutions for Surplus Heating and Cooling System in Combination with Ground Source Heat Pump/Chillers Trond Thorgeir Harsem, Member ASHRAE; Merethe Cecilie Lind; Karoline Husevåg Kvalsvik; Anette Fagerhaug Stephansen, PhD; Jan Kocbach, PhD .....	508
<b>OR-20-C065</b>	Legionella Intervention: Water Security and Resilience in Building Systems Richard Benkowski, Member ASHRAE; Kurt Steenhoek; Gerald Waites; Gregory Ballay; Scott Hamilton; Chris Carter .....	516
<b>OR-20-C066</b>	WITHDRAWN	
<b>OR-20-C067</b>	WITHDRAWN	
<b>OR-20-C068</b>	Numerical Study on the Effect of Low Frequency Vibration and Gravity on the Bubble Detachment Kai Han, PhD, PE, Member ASHRAE .....	525
<b>OR-20-C069</b>	An Environmental Building Design Using Natural Energy and the Thermal Storage Capacity of a Building Mass Masatoshi Kuboki, Member ASHRAE; Hisaya Ishino, PhD, Member ASHRAE; Kimiko Kohri, PhD, Member ASHRAE; Hiroshi Muramatsu .....	532
<b>OR-20-C070</b>	WITHDRAWN	
<b>OR-20-C071</b>	Method for Tuning a Chiller Power Estimation Model with a Very Limited Part Load Performance Data Set Marcelo Acosta, PEng, Member ASHRAE; Vladimir Suslov PhD, PEng .....	540
<b>OR-20-C072</b>	Evaluation of Fixed and Variable Speed Compressor Energy Consumption in a Residential Environment Before and After Building Renovations Jonathan P. Ore, Student Member ASHRAE; Nicholas P. Salts, Student Member ASHRAE; Eckhard A. Groll, Dr. Eng, Fellow ASHRAE .....	547
<b>OR-20-C073</b>	Use of Solar Thermal Collectors and a Horizontal Underground Loop in a Multi-Source Heat Pump System for Thermal Energy Storage Rui Miao, Student Member ASHRAE; Yao Yu, PhD, Associate Member ASHRAE; Gaylord Olson; Doug Selby; Laurie Catey, PE; Xiaou Hu, Student Member ASHRAE .....	556

## TECHNICAL PAPERS

<b>OR-20-001</b>	A Change Point Detection Algorithm with Application to Smart Thermostat Data Austin P. Rogers, PhD, Member ASHRAE; Fangzhou Gao; Bryan P. Rasmussen, PhD, PE, Member ASHRAE .....	567
<b>OR-20-002</b>	The Use of Reanalysis in ASHRAE Applications (RP-1745) Michael Roth, PhD, PEng, Member ASHRAE .....	580
<b>OR-20-003</b>	Quantifying Risk with Selection of the Natural Gas Maximum Daily Quantity Matthew M. Swanson, PhD, Associate Member ASHRAE.....	593
<b>OR-20-004</b>	History of Air Filtration and Air Cleaning: A 100 Year Review of Significant Advances and Related Influences in the Advancement of the Art and Science of Filtration and Air Cleaning H.E. Barney Burroughs, Presidential Fellow/Life Member ASHRAE; Brian Krafthefer, PE, Fellow/Life Member ASHRAE; Marilyn Listvan, PhD, Member ASHRAE...	601
<b>OR-20-005</b>	The History of Food Freezing Donald J. Cleland, PhD, Fellow ASHRAE .....	616
<b>OR-20-006</b>	The Evolution of ASHRAE's Electronic Communication and Publication Technology Jeff S. Haberl, PhD, BEMP, Fellow ASHRAE; Arthur D. Hallstrom, PE, BEMP, Fellow/Life Member ASHRAE; W. Stephen Comstock, Life Member ASHRAE; Eugene Stamper .....	622
<b>OR-20-007</b>	25 Year Evolution of a Worldwide Building Energy Simulation and Compliance Software Tool Liam Buckley, CEng, BEMP, Member ASHRAE .....	631
<b>OR-20-008</b>	ASHRAE History of a System: History of Trane's TRACE™ Software John Sustar, Member ASHRAE .....	640
<b>OR-20-009</b>	Carrier HAP and the Evolution of Energy Modeling Tools James Pegues, Member ASHRAE .....	644
<b>OR-20-010</b>	Effect of Water Cost on Optimal Control of a Chiller Plant with Variable-Speed Cooling Tower Fans O.A. Qureshi, PhD, Associate Member ASHRAE; P.R. Armstrong, PE, PhD, Fellow ASHRAE .....	651
<b>OR-20-011</b>	Specifics of Modern Tunnel Ventilation System in Delhi Mass Rapid Transit System Ashok Kumar Garg, CEng; Rajesh Kumar Jain, Member ASHRAE.....	671
<b>OR-20-012</b>	Enhanced Life-Cycle Cost Analysis of Sustainable Office Buildings Michael Zhivov, Associate Member ASHRAE .....	691
<b>OR-20-013</b>	Home Envelope Performance Evaluation Using a Data Driven Method Junke Wang, Student Member ASHRAE; Choon Yik Tang, PhD; Li Song, PhD, PE, Member ASHRAE.....	713
<b>OR-20-014</b>	Optimize a Chilled-Water Plant with Magnetic-Bearing Variable Speed Chillers Lei Wang, PhD, PE, Member ASHRAE; Yasuko Sakurai; David E. Claridge, PhD, PE, Fellow ASHRAE.....	725
<b>OR-20-015</b>	Potential Building Reheat Energy Saving Determination in Hot and Humid Climates Xiaoli Li; Juan-Carlos Baltazar, PhD, PE, BEMP, Member ASHRAE .....	736

<b>OR-20-016</b>	Pressure Loss Measurements in Typical Flexible and Sheet Metal Light-Commercial Duct Systems C. Kodali; A. Paruchuri; S. Idem, PhD, Member ASHRAE .....	747
<b>OR-20-017</b>	A Simple Airflow and Power Model of Fan-Coil Units with Permanent Split Capacitor Motors Dennis O'Neal, PhD, PE, Fellow/Life Member ASHRAE; Peng Yin, PhD, Associate Member ASHRAE .....	759
<b>OR-20-018</b>	Laboratory Performance Measurement of Blowers with Electronically Commutated Motors in Horizontal Low-Profile Fan Coil Units (RP-1741) Peng Yin, PhD, Associate Member ASHRAE; Beau Derouen; Albert McBride; Dennis O'Neal, PhD, PE, Fellow/Life Member ASHRAE.....	770
<b>OR-20-019</b>	Loss Coefficients for Internal Reinforcements Installed in a Phenolic Duct System (RP-1764) Avinash Paruchuri; Stephen Idem, PhD, Member ASHRAE .....	782
<b>OR-20-020</b>	Energy Master Planning: Identifying Framing Constraints that Scope Your Technology Options Terry Sharp, PE, Member ASHRAE; Matthias Haase, PhD; Alexander Zhivov, PhD, Fellow/Life Member ASHRAE; Behzad Rismanchi, PhD; Rüdiger Lohse; Jorgen Rose; Natasa Nord, PhD.....	789
<b>OR-20-021</b>	Integration of Resilience Goals into Energy Master Planning Framework for Communities Robert Jeffers, PhD; Amanda M. Wachtel; Alexander M. Zhivov, PhD, Fellow/Life Member ASHRAE; Calum B. Thompson, PE, Member ASHRAE; Avinash Srivastava; Patrick W. Daniels .....	807
<b>OR-20-022</b>	Energy Master Planning for Resilient Public Communities— Best Practices from U.S. Military Installations Angela Urban; Elizabeth Keysar, PhD; Kathleen Judd; Avinash Srivastava; Calum Thompson, PE, Member ASHRAE; Michael Case, PhD, Member ASHRAE; Alexander Zhivov, PhD, Life Member ASHRAE .....	828
<b>OR-20-023</b>	Net Zero Energy Strategies and Planning Support Tools for Campuses and Residential Neighborhoods in Germany Annette Roser, Karin Schakib-Ekabatan, Verena Weiler, Ursula Eicker, Rüdiger Lohse .....	849
<b>OR-20-024</b>	Measurements of Spray Water Evaporation Rates for an Inflatable Fabric Duct Cooling Tower S. Duong; R. Craven; S. Garner; S. Idem, PhD, Member ASHRAE .....	857
<b>OR-20-025</b>	WITHDRAWN	
<b>OR-20-026</b>	Existing Building Commissioning at a Community College Luke A. Madden, Student Member ASHRAE; Carlos Yagua, PE, Associate Member ASHRAE; Fred L. Schroeder, PE, Life Member ASHRAE; Juan-Carlos Baltazar, PhD, PE, BEMP, Member ASHRAE; David E. Claridge, PhD, PE, Fellow/Life Member ASHRAE; Walter H. Williams, PE; David Hoelke, Member ASHRAE .....	870
	Index of Papers, Volume 126, Part 1.....	882