

Environmental Engineering

Zhaojun Wang
Yingxin Zhu
Fang Wang
Peng Wang
Chao Shen
Jing Liu *Editors*

Proceedings of the 11th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC 2019)

Volume I: Indoor and Outdoor Environment

 Springer

Environmental Science and Engineering

Environmental Engineering

Series Editors

Ulrich Förstner, Technical University of Hamburg-Harburg, Hamburg, Germany

Wim H. Rulkens, Department of Environmental Technology,
Wageningen, The Netherlands

Wim Salomons, Institute for Environmental Studies, University of Amsterdam,
Haren, The Netherlands

More information about this subseries at <http://www.springer.com/series/3172>

Zhaojun Wang · Yingxin Zhu · Fang Wang ·
Peng Wang · Chao Shen · Jing Liu
Editors

Proceedings of the 11th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC 2019)

Volume I: Indoor and Outdoor Environment

Editors

Zhaojun Wang
Department of Building Thermal
Engineering, School of Architecture
Harbin Institute of Technology
Harbin, Heilongjiang, China

Yingxin Zhu
Department of Building Science
School of Architecture
Tsinghua University
Beijing, China

Fang Wang
Department of Building Thermal
Engineering, School of Architecture
Harbin Institute of Technology
Harbin, Heilongjiang, China

Peng Wang
Department of Building Thermal
Engineering, School of Architecture
Harbin Institute of Technology
Harbin, Heilongjiang, China

Chao Shen
Department of Building Thermal
Engineering, School of Architecture
Harbin Institute of Technology
Harbin, Heilongjiang, China

Jing Liu
Department of Building Thermal
Engineering, School of Architecture
Harbin Institute of Technology
Harbin, Heilongjiang, China

ISSN 1863-5520

ISSN 1863-5539 (electronic)

Environmental Science and Engineering

ISSN 1431-2492

Environmental Engineering

ISBN 978-981-13-9519-2

ISBN 978-981-13-9520-8 (eBook)

<https://doi.org/10.1007/978-981-13-9520-8>

© Springer Nature Singapore Pte Ltd. 2020

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd. The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Committees

Conference Organizing Committee

President

Prof. Zhaojun Wang, Harbin Institute of Technology, China

Technical Program Chair

Prof. Jing Liu, Harbin Institute of Technology, China

Advisory Chair

Prof. Yingxin Zhu, Tsinghua University, China

Secretary General

Peng Wang, Harbin Institute of Technology, China

Members

Fang Wang, Harbin Institute of Technology, China
Chao Shen, Harbin Institute of Technology, China
Jiankai Dong, Harbin Institute of Technology, China
Yanling Wang, Harbin Institute of Technology, China
Zhigang Zhou, Harbin Institute of Technology, China
Haiyan Wang, Harbin Institute of Technology, China
Xiumei Bai, Harbin Institute of Technology, China

Student Members

Yuchen Ji, Harbin Institute of Technology, China
Qingwen Xue, Harbin Institute of Technology, China
Xiaowen Su, Harbin Institute of Technology, China

Subei Bu, Harbin Institute of Technology, China
Xin Chen, Harbin Institute of Technology, China
Jing Du, Harbin Institute of Technology, China

International Advisory Committee

Edward Arens, University of California, Berkeley, USA
Chungyoon Chun, Yonsei University, South Korea
Richard Corsi, University of Texas at Austin, USA
Richard de Dear, The University of Sydney, Australia
Lin Duanmu, Dalian University of Technology, China
Xiumu Fang, Harbin Institute of Technology, China
Yi Jiang, Tsinghua University, China
Kwang-Woo Kim, Seoul National University, South Korea
Angui Li, Xi'an University of Architecture and Technology, China
Baizhan Li, Chongqing University, China
Yuguo Li, The University of Hong Kong, China
Junjie Liu, Tianjin University, China
Bjarne W. Olesen, Technical University of Denmark, Denmark
Andrew Persily, National Institute of Standards and Technology, USA
Shin-ichi Tanabe, Waseda University, Japan
Sven Werner, Halmstad University, Sweden
Hiroshi Yoshino, Tohoku University, Japan
Guoqiang Zhang, Hunan University, China
Xu Zhang, Tongji University, China
Jianing Zhao, Harbin Institute of Technology, China

International Scientific Committee

Alireza Afshari, Aalborg University, Denmark
Hazim Awbi, University of Reading, UK
Bin Cao, Tsinghua University, China
Guangyu Cao, Norwegian University of Science and Technology, Norway
Shijie Cao, Guangzhou University, China
Ping Cui, Shandong Jianzhu University, China
Lei Fang, Technical University of Denmark, Denmark
Guohui Feng, Shenyang Jianzhu University, China
Jun Gao, Tongji University, China
Naiping Gao, Tongji University, China
Weijun Gao, The University of Kitakyushu, Japan
Tomonobu Goto, Tohoku University, Japan

Runa T. Hellwig, Aalborg University, Denmark
Jan Hensen, Eindhoven University, Netherlands
Sabine Hoffmann, Technische Universität Kaiserslautern, Germany
Tianzhen Hong, Lawrence Berkeley National Laboratory, USA
Yiqiang Jiang, Harbin Institute of Technology, China
Xianting Li, Tsinghua University, China
Xiangli Li, Dalian University of Technology, China
Zhengrong Li, Tongji University, China
Zhiwei Lian, Shanghai Jiao Tong University, China
Borong Lin, Tsinghua University, China
Zhang Lin, City University of Hong Kong, China
Xiaohua Liu, Tsinghua University, China
Zhiwen Luo, University of Reading, UK
Jianlei Niu, The Hong Kong Polytechnic University, China
Atila Novoselac, University of Texas at Austin, USA
Yiqun Pan, Tongji University, China
Menghao Qin, Technical University of Denmark, Denmark
Mattheos Santamouris, University of New South Wales, Australia
Chandra Sekhar, National University of Singapore, Singapore
Stefano Schiavon, University of California, Berkeley, USA
Marcel Schweiker, Karlsruhe Institute of Technology, Germany
Li Song, University of Oklahoma, USA
Fu-Jen Wang, National Chin-Yi University of Technology, China
Gang Wang, University of Miami, USA
Leon Wang, Concordia University, Canada
Shengwei Wang, The Hong Kong Polytechnic University, China
Yi Wang, Xi'an University of Architecture and Technology, China
Wei Xu, China Academy of Building Research, China
Da Yan, Tsinghua University, China
U Yanagi, Kogakuin University, Japan
Hongxing Yang, The Hong Kong Polytechnic University, China
Xudong Yang, Tsinghua University, China
Runming Yao, University of Reading, UK
Yang Yao, Harbin Institute of Technology, China
Yonggao Yin, Southeast University, China
Yanping Yuan, Southwest Jiaotong University, China
Zhiqiang (John) Zhai, University of Colorado at Boulder, USA
Hui Zhang, University of California, Berkeley, USA
Jili Zhang, Dalian University of Technology, China
Linhua Zhang, Shandong Jianzhu University, China
Quan Zhang, Hunan University, China
Tengfei (Tim) Zhang, Dalian University of Technology, China

Yinping Zhang, Tsinghua University, China

Yufeng Zhang, South China University of Technology, China

Xudong Zhao, University of Hull, UK

Xiang Zhou, Tongji University, China

Organization

Organized by

Host and Organizer



Harbin Institute of Technology

Co-organizer



Tsinghua University

Supported by



American Society of Heating, Refrigerating and Air-Conditioning Engineers



Journal of Heating, Ventilation and Air Conditioning



The Chinese Association of Refrigeration (CAR)



The Chinese Committee of Heating, Ventilation and Air Conditioning (CCHVAC)

List of Plenary Lectures

Speakers	Affiliation	Topic
Yi Jiang	Tsinghua University, China	The Approach for Building Energy Efficiency in Emerging Economies Countries
Bill Bahnfleth	The Pennsylvania State University, USA	Promise and Practicalities of Smart Systems
Bjarne W. Olesen	Technical University of Denmark, Denmark	State of the Art of HVAC Technology in Europe
Yingxin Zhu	Tsinghua University, China	How to Create Comfortable and Healthy Indoor Environment?—A New Challenge for Sustainable Building
Katsunori Nagano	Hokkaido University, Japan	Contribution of Heat Pumping Technologies for the Green Environment and Our Life
Rajan Rawal	CEPT University, India	Thermal Comfort for All: Setting up a Stage
Vladimir G. Gagarin	Moscow State University, Russia	Structure and Development of the System of Regulatory Documents in Russia on the Thermal Performance and Energy Saving of Buildings
Zhaojun Wang	Harbin Institute of Technology, China	Thermal Comfort and Thermal Adaptation in the Severe Cold Area, China

Preface

The International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC) series was initiated by Tsinghua University of China in 1991. It has been a premier international conference on heating, ventilating, and air conditioning (HVAC) in China and has played a significant role in presenting newly found research results and exchanging ideas among colleagues from academics, research organizations, and industry in the field. The 11th ISHVAC (ISHVAC 2019) was held from July 12 to 15, 2019, in Harbin, China, hosted by Harbin Institute of Technology (HIT), and Prof. Zhaojun Wang from HIT was the president of ISHVAC 2019.

In developed countries, buildings use 40% of the primary energy, while in developing countries like China, buildings use one-third of the primary energy. Thus, energy used in buildings is very significant, and a majority of the energy used in buildings is by HVAC systems that should create a thermally comfortable and healthy indoor environment for their occupants. However, the indoor environment created is far from ideal because of poor design, operation, and occupant intervention. Therefore, ISHVAC 2019 focused on not only HVAC but also indoor environmental quality, health, thermal comfort, human activities, energy efficiency, renewable energy, etc. The conference provided a great opportunity to exchange new ideas and the state-of-the-art sciences and technologies, to identify solutions for problems in the built environment, and to build partnerships among engineers, architects, environmental scientists, facility managers, HVAC system manufacturers, and policy-makers.

The themes of this conference include: indoor and outdoor environment; heating, ventilation, air conditioning, and refrigeration; and building and energy. More than 600 full papers were received, of which 543 were accepted and 407 were included in the proceedings. There were eight keynote lectures, 15 workshops, 56 parallel sessions, and one poster session. More than 500 experts and scholars from 20 countries or regions attended the conference, of which more than 80 were foreign guests. The participation of many internationally renowned experts and scholars has raised the level of ISHVAC 2019. The conference had the following features:

- The conference invited prominent Indian and Russian scholars to present in plenary sessions, and their presentations were of significance to the study of global climate and energy consumption.
- Many outstanding scholars were invited to organize 15 workshops, focusing on hot issues including thermal environment and thermal comfort, indoor environmental quality, pollutant transmission and control, human behaviors and building energy consumption simulation, smart heating, evaporative cooling, and heat pump.
- During the conference, the Asian HVAC Alliance was established. We hope that the ISHVAC series would become a grand event in the field of HVAC in Asia in the future, like CLIMA conferences in Europe and ASHRAE conferences in North America.

We would like to appreciate the international advisory committee and scientific committee for their hard work and efforts in reviewing papers and providing the support needed. We would also like to thank the co-organizer Tsinghua University and co-sponsors such as ASHRAE, Journal of HV&AC, the Chinese Association of Refrigeration, and the Chinese Committee of Heating, Ventilation and Air Conditioning (CCHVAC).

Harbin, China
Beijing, China
Harbin, China
Harbin, China
Harbin, China
Harbin, China

Zhaojun Wang
Yingxin Zhu
Fang Wang
Peng Wang
Chao Shen
Jing Liu

Editors of the Proceedings of ISHVAC 2019

Contents

Correlated Thermophysiological Parameters of Human Body in the Moderate Thermal Environment at Sedentary Activity Level.	1
Lijuan Wang, Zefeng Chen and Minzhou Chen	
Design and Research on New Green Nomadic Tents for Tibetan Nomads in Western China	9
Xiang Zhao and Enshen Long	
CFD-Based Numerical Method for Temperature Set-Point Commissioning and PMV Assessment of Occupied Individual Air-Conditioning Zone	19
Xiang Deng, Xue Xue and Bugong Xu	
Evaluation on the Performance of the Ventilation and Dust Removal System in the Welding Plant	29
Xinyue Mao, Bin Zhou, Lan Zhu, Min Hou, Huifang Liu and Kun Liu	
Phthalate Esters in Dust from Households with Schoolchildren in Changsha, China: Distribution and Exposure Assessment	37
Jinhua Hu, Nianping Li, Xiaoli Hao and Huaidi Qu	
Predicting Sweat Rate of Chinese People under Moderate Activities Based on Experiments	47
Haiying Wang, Guoqing Li and Chonggen Shi	
Curve Analysis of Airborne BTEX Concentration in Vehicles	57
Daocong Qin, Jie Hu, Bing Guo and Xiaokai Chen	
Numerical Study on Pollutant Removal Performance of Vortex Ventilation in Different Pollutant Locations	67
Zhixiang Cao, Chao Zhai, Tongtong Zhao and Yi Wang	

Numerical Study on Thermal Management of Data Center Integrated with Underfloor Vertical Baffles 77
Yiwen Zhang, Kai Zhang, Jinxiang Liu, Fei Li and Jun Bao

Study on the Effects of Channel Deployment in a S-Shaped Liquid Cooling Heat Sink for Electronic Chip Cooling 87
Zhihao Lu, Kai Zhang and Jinxiang Liu

Determining Moist-Based Ventilation Rates for Residential Buildings with Low-Infiltration in China: A Preliminary Discussion 97
Shengyi Tang, Wei Ye, Xing Su and Xu Zhang

Numerical Comparisons on Heat-Source-Targeted and Large-Area Spray Cooling for an Impinging Jet at High Temperature in a Confined Space 107
Chengqiang Zhi, Yixiang Huang, Qianru Zhang, Wei Ye and Xu Zhang

Long-term Variations of Indoor Formaldehyde Concentration and Emission Characteristics of Building Materials in Chinese Residences 115
Weihui Liang

Winter Indoor and Outdoor Air Quality Test and Analysis for Secondary School Classrooms in North China 121
Yunxia Qu, Yingbo Ji, Yuanzheng Jiang and Zongluo Zhang

Experimental Evaluation of the Indoor Human Thermal Comfort under Different Environments Based on Heart Rate Variability Analysis 131
Hui Zhu, Hanqing Wang, Hua Su, Zijian Xiao, Xiaogen Kuang and Jinping Zhao

The Measured Analysis of Flow Fields and Pollutants in the City Street 141
Huifen Zou, Yixin Ma and Zongkun Li

Determination of the Three Key Parameters Estimating Indoor Air Filtration Load Regarding PM_{2.5} Penetration Through Infiltration 153
Ziguang Chen, Chao Chen, Guoqing Cao, Zixi Li, Yan Wu, Guanpeng Cao, Yirong Yuan, Xuan Li and Qinqiang Hu

Characteristics of Indoor Combined Pollution Induced by Ozone under Different Occupant Density Conditions 163
Jun Wang, Tong Zhou, Hao Liang and Feng Xiong

Theoretical Model for Surface Filtration Pressure Drop and Accurate Measurement Method of Dust Cake Porosity 173
Wanyi Zhang, Shiming Deng and Zhongping Lin

Visible Photocatalysis of a Building Glass Coated with N-F-TiO₂/rGO	181
Qiwen Jiang, Jialin Hou, Jialu Liu, Yukun Fu and Yanhua Liu	
Field Study on Indoor Thermal Environment of Traditional Residence in Guilin in Winter	191
Wenheng Zheng and Shaoying Su	
A Fast and Accurate Airtight Chamber Method for Determining the Characteristic Parameters of VOC Emission from Building Materials	201
Xiaojun Zhou, Yanfeng Liu, Cong Song, Xinke Wang and Fenghao Wang	
An Experimental Study of Indoor Air Distribution Characteristics in a Room with Mixing Ventilation and Chilled Ceiling	211
Jie Gao, Pin Lv, Xiaozhou Wu, Shugang Wang and Fenghao Wang	
Adaptive Behaviors of Thermal Environment Based on Thermal Comfort for the Elderly People	221
Xiaoping Yu, Xiaolin Wu, Xue Huang and Guobing Shi	
A Superposition Method to Predict Indoor Temperature Distribution with Convective Heat Gain/Loss Through the Building Envelope	229
Shuai Yan, Xiaoliang Shao and Xianting Li	
Is There Any Difference in Indoor Environmental Perceptions between People with and without Respiratory Allergy?	239
Dandan Li, Xiaojing Zhang, Jingchao Xie and Jiaping Liu	
Annual Thermal Dynamic Characteristic of Underground Cave Dwellings in West Area of Henan	249
Xi Zhao, Jiayin Zhu and Yingfang Liu	
Research on Experiment Method of Intelligent Environment and Human Perception—Construction of Visualization Platform	259
Jie Deng, Bin Chen and Shibo Wang	
Influence of Warm Exposure on Thermal Perceptions and Control Behaviors Over Indoor Environments	269
Jiamin Lu, Nianping Li, Yingdong He, Yangli Han, Xuemiao Fang and Linxuan Zhou	
Investigations for Reducing Personal Exposure to PM_{2.5} from Residential Chinese Cooking Based on CFD Simulation	279
Yuejing Zhao and Bin Zhao	
Estimated Secondary Organic Carbon (SOC) in PM_{2.5} from Chinese Cooking via Minimum OC/EC Ratio Method	287
Yuejing Zhao and Bin Zhao	

Empirical Study on the Comprehensive Impact of Outdoor Climate on Building Indoor Environment and Human Perception	293
Xinying Fan and Bin Chen	
Impact of Seasonal Trends and External Windows Structures on Both Indoor PM_{2.5} Pollution Level at Several Residential Buildings in Beijing, China	303
Ziguang Chen, Yan Wu, Guoqing Cao, Xuan Li and Mingjian Zhang	
Effect of Two Heating Methods on Sleep Quality in the Elderly	311
Lulu Xia, Li Lan and Jieyu Tang	
Study on Thermal Environment of Composed Air Carrying Energy Radiant Air-Conditioning System	321
Pei Peng, Guangcai Gong, Riming Liu, Jie Han, Yongchao Liu and Junwei Liu	
Thermal Performance Simulation Analysis of the Novel Micro Heat Pipe	331
Pei Wang, Yaping Zhang, Yongxin Guo and Yao Chen	
Comparative Study on Thermal Sensation and Skin Temperature Passing Different Transitional Spaces with or without Air-Conditioning in a Shopping Mall	339
Jie Han, Wenheng Zheng, Rong Hu, Zhihong Yang, Guoqiang Zhang, Per Heiselberg and David Hou Chi Chow	
A Performance Comparison of Three Ventilation Modes in an Office with Internal Partitions	351
Chao Huan, Fenghao Wang, Shuaishuai Gao, Lang Liu, Bo Zhang and Pengfei Tao	
Investigation into the Adaption Thermal Comfort in the Office Prefab House of Building Site in Guangzhou	363
Chuhao Fu, Zhimin Zheng, Zhaosong Fang and Zhaoliang Ji	
Residential Thermal Environment and Thermal Sensation Model of the Elderly in Hunan Province in Winter	373
Xuemiao Fang, Nianping Li, Zhaoxin Wei, Xiaohang Shen and Haijiao Cui	
A Central Air Conditioning Control Strategy to Enhance Thermal Comfort in Library Buildings	385
Minglin Zheng, Zhenyuan Dong, Qianjia Xie, Xinyi Wu, Zexi Lin, Ziyi Zhang, Weitang Liang, Weina Chen, Cho Kwong Charile Lam and Jian Hang	

A Review on the Method of Field Measurement at Fixed Points for Outdoor Thermal Environment	395
Xiaoqing Zhou, Yaru Xu and Li Li	
Size-Dependent Removal Efficiency of Mechanical Ventilation System with Air Filtration Unit for Nanoparticles	403
Chen Chen and Bin Zhao	
Micro-Scale Thermal Sensitivity Mappings of Human Body	411
Maohui Luo, Hui Zhang, Edward Arens and Zhe Wang	
Age-Related Thermal Comfort in a Science Museum with Hot-Humid Climate in Summer	421
Pengnan Li, Ye Liu and Jianfei Dong	
The Prevalence of Obesity in Children Aged 4–6 Years of Shanghai and the Effect of Early Family Care	433
Xionsgi Jin, Chen Huang, Chunxiao Su and Zhijun Zou	
CFD Simulations on Temperature Control for an Organic Glass Sphere with High-Heat-Flux Sources	441
Wenxuan Zhao, Wei Ye, Chao Wu and Xu Zhang	
Sensitive Analysis of Factors on Thermal Environment in the Waterfront Area	451
Xiaocheng Song, Jing Liu, Yu Zhao and Jie Gao	
Effect of Particle Composition on the Continuous Loading Performance of Medium- and High-Efficiency Electret Media	461
Yongxiang Wang, Zhongping Lin and Wanyi Zhang	
Measurement and Analysis of the Concentration and Size Distribution of Welding Fume in a Confined Space	469
Chengjun Li, Hanqing Wang, Wang Li, Yongjun Ye and Minqiang Wang	
Variations in Volatile Organic Compounds (VOCs) in Residential Buildings during Construction Stage	481
Ke Wu, Weihui Liang and Weilin Cui	
Influence of Human Activities on Airflow and Pollutant Distribution in the Waiting Area in a General Hospital	491
Min Chen, Yintao Yin, Jishun Zhang and Chuanhui Zhou	
Characteristics of Pollutant Dispersion for Movement of a fleet of vehicles Inside a Road Tunnel Using Dynamic Mesh	503
Xiaocheng Song, Yu Zhao and Chenglong Jiang	
Numerical Simulation Analysis of Formaldehyde Pollution Control in Newly Decorated Buildings	513
Dongqian Li, Guojie Chen and Qinghai Luo	

Study on Ventilation Rate of Elevator Shaft Installed in Existing Residential Buildings—A Case Study of Chongqing 523
Xue Huang, Xiaoping Yu, Xiaolin Wu and Guobing Shi

Case Study on the Pedestrian Wind Environment of Commercial Streets in Beijing and Tokyo Based on CFD Simulation 533
Zhongqing Yang and Xiaojing Zhang

Study on the Influence of Spacing of Two Different Heat Sources on Aerosol Diffusion in Kitchen 543
Changfa Ji, Rong Chen, Yujiao Zhao and Haoran Jin

Experimental Study on Thermal Environment and Stratified Air-Conditioning Load of Large-Space Building with Low-Sidewall Air Supply under Periodic Thermal Disturbance 553
Chen Huang, Liang Qiao, Tianyu Bai, Haidong Wang, Zhijun Zou and Liugen Lv

Research on More Effective Local Cooling Ways to Human Thermal Comfort in Hot Environment 563
Yiwen Luo, Zhiwei Lian, Yingli Xuan and Weirong Zhang

Comparative Study on Thermal Comfort of People from Different Climate Zones in Summer 573
Qianqian Liu, Haiyan Yan, Hanyu Wang, Hao Zhang and Mengru Dong

Correlation between Indoor and Outdoor Particulate Matter Concentration in Urban Residential Buildings 583
Meng Yu, Huixing Li, Ying Guan and Ruiyang Gao

Experimental Study on Thermal Environment and Stratified Air-Conditioning Load of Scaled Model Laboratory with Low-Sidewall Air Supply under Step Thermal Disturbance 603
Chen Huang, Yufeng Miao, Yang Liu, Ruibin Li, Yuantao Xue, Haidong Wang and Fei Wang

Analysis of Inside Thermal Response Characteristic by Radiant Cooling System for Different-Level Energy-Efficient Building 613
Zhengrong Li, Dongkai Zhang, Shunyao Lu and Xiangyun Chen

Numerical Simulation of New Ventilation Mode in Multiple-Bed Hospital Wards 623
Hongmei Zhang, Guizhi Liu, Zhouyun Xu and Di Liu

Investigation and Study on Indoor Environment of the Elderly in Hot and Humid Area—A Case Study of Guangzhou 633
Bixia Xu, Qiong Li, Hiroshi Yoshino, U. Yanagi, Kenichi Hasegawa and Peijie Tang

Dynamic Thermal Behavioral Adaptation Process of Migrants: A Long-Term Tracked Field Study	639
Yu Dong, Yanfeng Liu, Cong Song and Yuan Shi	
Numerical Study of Gas–Solid Two-Phase Flow Field in Fiber Filter	649
Guohui Feng, Zheng Zhang and Yixian Zhang	
Association between Nighttime Air Infiltration of Bedroom and Characteristics of Residential Building in Shanghai	659
Chen Huang, Qinhou Zhang, Zhanyuan Qing, Chunxiao Su and Zhijun Zou	
Field Study on Thermal Comfort and Adaptive Behaviours with a Personal Heating Device in Hunan	669
Linxuan Zhou, Nianping Li, Yingdong He, Jing Zhang, Jiamin Lu and Yangli Han	
Experimental Study on Occupant Control Behaviors Over a Thermostat of Air-Conditioning System and a Ceiling Fan	679
Yangli Han, Nianping Li, Yingdong He, Jiamin Lu, Linxuan Zhou and Hui Zhang	
Parametric Optimization of Novel Partition-Type Radiant Heating Terminals to Improve Human Comfort in Cool Environments: Simulations Based on Experimental Results	689
Meng Wang, Nianping Li, Yingdong He, Jinbo Yan, Meiyao Lu and Fenglin Zhang	
Analysis of Indoor Thermal Environments and AC-Use Behaviours in an Office Building	699
Jing Zhang, Nianping Li, Linxuan Zhou, Jia Li, Yingdong He and Xuemiao Fang	
Estimation of Human Exposure and Environment Burden of Disease Caused by PM_{2.5} Pollution in Beijing, China	709
Yumeng Liu and Bin Zhao	
Reduction of Human Exposure and Premature Deaths by Indoor PM_{2.5} Cleaning in Beijing, China	717
Yumeng Liu and Bin Zhao	
Influences of Different Meteorological Parameters on Outdoor Thermal Comfort in Cold Climate Regions in China	725
Kuixing Liu, Tingting Gan, Wenyu Liu, Dayi Lai and Gang Liu	
Research on Thermal Comfort of University Libraries in Summer of Guangzhou	735
Ting Peng, Zhaosong Fang, Zhimin Zheng, Zhaoliang Ji and Qianlin Li	

Cooling Potential of Natural Ventilation for Passenger Stations in Southern China	745
Yijia Hao, Qi Hu, Yan Tong, Jianlin Wu, Zhantao Xu, Ying Ji and Zigao Yu	
Investigation into the Adaption of PMV to Evaluation of the Medical Staff in Hospitals in Guangzhou	755
Xiangfei Ji, Zhaosong Fang, Zhimin Zheng and Zhaoliang Ji	
Indoor Thermal Environment Test and Evaluation of Mobile Public Toilets in Summer	765
Ruixin Li, Yiwan Zhao, Jiayin Zhu and Weilin Li	
Effects of Space Geometry, Season and Weather Condition on Different Components of Outdoor Thermal Radiation	777
Kuixing Liu, Wenyu Liu, Tingting Gan, Dayi Lai and Gang Liu	
Comparisons of the Different Discharge Performances and the Effect of Long-Term Loading with the Liquid Aerosol on Electret Media ...	787
Yongxiang Wang, Zhongping Lin and Wanyi Zhang	
Study on Optimization of Winter Ventilation Strategy for Newly Decorated Kitchen in Severe Cold Region	797
Kailiang Huang, Jun Wang, Guohui Feng, Jiasen Song and Wen Sun	
A Micro-nanocomposite Electret Filter for High-Efficiency Particulate Matter Filtration	807
Shuzheng Li, Rongrong Cai and Lizhi Zhang	
The Impact of History of Using Air-Conditioning on Students' Heat-Stroke in Summer Military Training	817
Qianni Liu and Yufeng Zhang	
Analysis of Indoor Formaldehyde Pollution in Mechanical Fresh Air System Residential Buildings in Liaoning Area in Winter	827
Kailiang Huang, Wen Sun, Guohui Feng, Jiasen Song and Jun Wang	
Experimental Measurement on the Thermal Environment of the Sidewalk	837
Xiaoqing Zhou, Qingliang Li and Li Li	
Thermal Performance of Various Microencapsulated Phase Change Material Drywalls Integrated into Buildings: A Numerical Investigation by ESP-r	847
Weiguang Su, Jo Darkwa, Georgios Kokogiannakis and Yilin Li	
An Experimental and Numerical Study on the Effect of Column Layout on Air Distribution and Performance of Column Attachment Ventilation	857
Haiguo Yin, Linna Li, Rui Wu, Yuanyuan Wang and Angui Li	

Study on Thermal Comfort of Residential Nearly Zero Energy Buildings Based on Human Thermal Adaptation	867
Guohui Feng, Kairan Wang, Xiaolong Xu, Yue Wang and Xianshi Fang	
Effect of Acclimatization and Thermal History on Outdoor Thermal Comfort in Hot-Humid Area of China	877
Cho Kwong Charlie Lam, Shuhang Cui, Jiarui Liu, Xiangrui Kong and Jian Hang	
A Survey of Exposure to Formaldehyde and TVOCs in High-Rise Residential Buildings	887
Yuesheng Fan, Xin Zhang, Huan Wang, Jiajing Liu and Shanshan Peng	
Study on Indoor Air Quality of Residential Buildings in the Severe Cold Regions of Northeastern China in Winter	897
Kailiang Huang, Jiasen Song, Guohui Feng, Qunpeng Chang, Jun Wang and Wen Sun	
Research on the Inter-zonal Heat Transfer Coefficient in Thermally Stratified Environment of Floor-Level Air-Supply System	905
Xinqi Yang, Haidong Wang and Yuantao Xue	
Experimental Study of Purification Performance of PM_{2.5} by Air Filters at Different Grades	915
Xin Zhang, Yuesheng Fan, Huan Wang, Wei Xie, Liang Liu and Jie Liu	
Filed Study on Human Thermal Comfort for the Elderly in Xi'an, China	925
Wuxing Zheng, Dong Che, Fangle Zhou, Yu Liu and Cho Seigen	
Use Side-Supply Airflow to Enhance Heat Transfer of Radiant Heating Ceilings for Producing a Better Indoor Thermal Environment in Winter: A Simulation Study	935
Meiyao Lu, Nianping Li, Yingdong He, Fenglin Zhang, Chenyu Huang and Xuemiao Fang	
Healthy Ranking of Indoor Risk Factors for Childhood Asthma: A Cross-Sectional Study in Shanghai	943
Chanjuan Sun, Shijie Hong, Chen Huang, Zhijun Zou and Chunxiao Su	
A New Correcting Algorithm for Thermal Response Test Data Evaluation	953
Xuedan Zhang, Tiantian Zhang, Yiqiang Jiang and Bingxi Li	
Associations of Indoor CO₂ Concentration with Sleep Quality and Other Human Responses	963
Guanzhang Luo, Xiaojing Zhang, Jingchao Xie and Dandan Li	

Study on Thermal Comfort of Beijing Subway in Summer	971
Zhonghai Chen, Zhongfeng Liu, Lang Xie, Wei Yu, Song Pan, Zhilin Guo, Yiqiao Liu and Qingping Li	
Asymmetrical Distribution of Solar Energy in Buildings with Glazing Facade	979
Zhengrong Li, Shun Yao Lu, Qun Zhao and Fujian Jiang	
The Influence of the Geometric Characteristics of Street Valley on the Wind Environment	989
Huifen Zou, Huameng Xu, Lilei Zhao and Mingyuan Li	
The Determination of Key Parameters in Adaptive Thermal Comfort Model	999
Qian Chai, Liu Yang, Honglian Li and Kailin Lv	
Experimental Study on Indoor Thermal Environment of Radiant Floor Heating System Based on Micro-Heat Pipe Array	1007
Yunhan Liu, Zhenhua Quan, Yaohua Zhao, Ruixue Dong and Xianlai Fan	
Study on the Angle of Flame Tilt under Longitudinal Ventilation in Tunnel	1017
Xianlai Fan, Yanfeng Li, Junmei Li, Yang Tian, Yunhan Liu, Huiqiang Liu and Shouchong Zhao	
Experimental Study on Particle Distribution under Stratified Air-conditioning in Large Space Building	1027
Fei Wang, Zhenhai Li, Xin Wang, Qidong Li and Chen Huang	
Discussion on the Characteristics of Preschool Childhood Asthma Recovery in the Short Term	1037
Chen Huang, Zhenzhen Xia, Li Shen, Chanjuan Sun and Zhijun Zou	
University Building Energy Consumption and Indoor Environment Quality: A Review of Optimization Strategies	1045
Xue Tan, Jun Guan, Zhiwei Zhang, Shuqin Chen, Qiang Guo, Jian Xu and Wei-hua Song	
A Primary Study of New Indexes for Air Pollutant	1053
Jiamin Guo, Peng Xue, Mengjing Zhao, Guangtao Fan, Bohan Ding and Jiaping Liu	
Simulation and Optimization Analysis of Summer Indoor Thermal Environment for School Buildings in Hot Summer and Cold Winter Zone	1063
Lili Zhang, Yuyao Hou, Dong Wei, Zu'an Liu, Jiawen Hou, Junfei Du and Qiong Shen	

A Thermal Comfort Field Study of Naturally Ventilated Classrooms during Spring and Autumn in Xi'an, China	1073
Jialu Liu, Xian Yang and Yanhua Liu	
Year-Long Survey, Influencing Factors and Improvement Strategies of Indoor Air Environment in Guangzhou Office Buildings	1083
Chihui Zhu, Wei Zhou and Hai Liu	
Effect of Urban Park Landscape on Outdoor Temperature Environment in Summer	1093
Lili Zhang, Dong Wei, Yuyao Hou, Zu'an Liu, Jiawen Hou, Junfei Du and Qiong Shen	
Numerical Simulation of Self-balanced Warm-Air Heating in Boiler-Room of Thermal Power Plant in Winter	1103
Huizhe Cao, Yuhang Wang, Tianli Zhao, Jiagang Qu, Jinfang Zhai and Weihua Cai	
Study on the Influence of Thermal Properties of Building Envelope on Indoor Pollutant Diffusion	1113
Ruijun Wang and Ye Wang	
IAQ+DeST Joint Software and Its Application Study	1123
Yiwen Jian, Ruimin Guo, Xiaoxiao Liu and Xu Wang	
The Deposition and Desorption of PM_{2.5} in Porous Materials Beds	1133
Yuan Wang, Shugang Wang, Jihong Wang, Tengfei Zhang and Zhenjun Ma	
Numerical Simulation of Transient Cavitating Flows in Pipeline Systems	1141
Qiang Sun, Yuebin Wu and Huan Liang	
Distribution of Air Change Rates in Residential Buildings in Beijing, China	1149
Mingyao Yao and Bin Zhao	
Numerical Analysis of the Dynamic Heat and Moisture Coupling Transfer Within Typical Building Walls in Severe Cold Region of China	1157
Hongrui Zheng, Fang Wang, Haiyan Wang and Yanling Wang	
Pinch-Point Temperature Difference Analysis of Dual-Loop Organic Rankine Cycle	1169
Xinyu Li, Tao Liu, Lin Chen and Peng Li	

A Comparison of Thermal Comfort of People from Buildings with Centralized Air-Conditioning Systems and Split Air-Conditioners	1181
Zhongjun Zhang, Yufeng Zhang and Adnan Khan	
Evaluation of Mould Growth on Wall Surface by Different Models . . .	1191
Jie Song, Jingchao Xie, Linna Xie, Guozhu Li, Ran Zhang and Jiaping Liu	
Optimization Design on Ventilation Openings of Super Large Circular Coal Storage Dome	1201
Yu Zhou, Chao Chen, Yaohua Hou, Chao Sun, Hexiang Nie and Shen Wei	
Experimental Investigation About Visual Comfort Based on Evoked Potentials	1211
Hongyu Guan, Songtao Hu, Mengke Liang, Yongming Ji and Guodan Liu	
Investigation of Dynamic Thermal Comfort and Air Velocity Preference in Different Transient Environments in Summer	1223
Ge Yao, Nianping Li, Zhibin Wu, Chang Xu and Jing Zhang	
Exploring Thermal Comfort and Dynamic Work Performance in a Different Transient Thermal Environment in Summer	1233
Chang Xu, Nianping Li, Zhibin Wu, Ge Yao and Jing Zhang	
Experimental Study on Improving Thermal Environment in Solar Greenhouse with Active–Passive Phase Change Thermal Storage Wall	1243
Tuo Wang, Yong Guan, Wanling Hu, Huijun Yang, Jianxuan Guo and Renli Zhang	
Research on the Influence of Fresh Air on Indoor Air Distribution and Energy Consumption in Heating Room	1253
Hanyu Yang, Enshen Long and Jin Li	
Field Monitoring of the Natural Ventilation Rate of Residential Buildings in Beijing	1263
Rong Sun, Yiwen Jian and Xu Wang	
Measurement Study on Outdoor PM2.5 Affecting Occupants’ Window Opening Duration in Residential Buildings in Beijing, China	1273
Xu Wang, Yiwen Jian, Ruimin Guo and Yuchen Hou	
Study on Ventilation Characteristics of High-Drop Spiral Tunnel during Operation Period	1283
Shoubao He, Yan Wu and Jianbin Zang	
Comprehensive Effects of Temperature, Relative Humidity, and Illumination on Sleep Quality	1295
Ting Cao, Zhiwei Lian, Ryota Miyazaki and Jianke Bao	

Study on Influence of Altitude on Indoor Temperature Distribution of a Heating Room	1305
Jin Li, Enshen Long, Hanyu Yang, Min Wang and Ziyun Wang	
A Multiscale Fractal Model for Predicting the VOC Diffusion Coefficient of Fabric	1315
Ruixue Ma, Xiaojun Zhou, Fenghao Wang, Xinke Wang and Zhihua Wang	
The Effects of Light Correlated Color Temperature and Illuminance Level on Mood States in Offices	1325
Sarra Hadji, Lulu Xia, Li Lan, Ruiqi Liu and Zhiwei Lian	
Numerical Simulation of Different Ventilation Modes on the Concentration Distribution of Fine Particulate Matter (PM_{2.5}) in Human Respiratory Area	1335
Yongyi Huang, Qingqing Pei, Yajia He and Song Xiong	
Study on the Law of Diffusion of Sudden Pollutants in Subway Ventilation Shaft	1345
Xinyi Lu, Yan Wu, Jingwei Wu and Jianbin Zang	
Analysis of Intelligent Heating Strategy and Energy-Saving Potential of Campus Buildings	1355
Dongjie Zhang, Changhong Zhan, Yongjie Wang, Lin Chen, Zhigang Zhou, Jiankai Dong, Yongxin Liu and Xiumu Fang	
Research on the Influence of Seasonal Behaviors on the Improvement of Person's Climate Adaptability	1363
Yubei Liu and Bin Chen	
Modeling Impacts of Dynamic Ventilation Strategies on Indoor Air Quality and Energy	1373
Jiajia Zhou, Baoping Xu and Sibin Bai	
Comparison of Airflow and Pollutant Dispersion in Multi-room Buildings under Different Cross-Ventilation Patterns	1383
Xiangxiang Lv, Xiaoping Liu, Mei Wu and Zhen Peng	
Calculation of the Mean Skin Temperature in the Non-uniform Thermal Environments	1393
Yuemei Wang and Zhiwei Lian	
Effect of Indoor Particle Sources on Indoor PM_{2.5} Distribution in Passive House with Displacement Ventilation	1405
Qingwen Xue, Zhaojun Wang and Zhiyi Yu	
Adaptive Window Opening Behavior in Office Buildings in the Severe Cold Region, China	1415
Xiaowen Su and Zhaojun Wang	

Simulation and Analysis on Thermal Comfort of Air-Conditioned Room with Different Air Supply Temperature and Velocity	1425
Kezhi Yu, Yin Li, Zhaoyang Cao and Yanling Liu	
Simulation of Indoor Comfort for Different Air Supply Modes	1435
Kezhi Yu, Yutong Yang, Zhaoyang Cao and Yanling Liu	
Test Study About PM_{2.5} Penetrations Through Building Envelope	1443
Yanling Wang, Fang Wang, Haiyan Wang, Huihui Zhang and Juanjuan Li	
Childhood Asthma and Allergic Symptoms Associated with Residential Dampness and Undesirable Odors	1451
Subei Bu, Yanling Wang, Fang Wang, Haiyan Wang and Yufei Tan	
Daylight Illuminance Analysis for Classrooms with Prism Daylight Redirecting Fenestrations	1459
Peng Lin, Zhen Tian, Qilin Cai, Cunhui Cao and Guipeng Lin	
Comfortable Indoor Environment with Kang	1469
Zhaojun Wang, Yushan Wang and Teng Zhang	

Correlated Thermophysiological Parameters of Human Body in the Moderate Thermal Environment at Sedentary Activity Level



Lijuan Wang, Zefeng Chen and Minzhou Chen

Abstract In this study, the correlation of human physiological parameters to ambient temperature was evaluated in the temperature range of 21–29 °C. The physiological parameters investigated herein included mean skin temperature (MST), heart rate, the ratio of absolute power in low frequency (LF) and high frequency (HF) bands (LF/HF ratio). The results of ANOVA and R test indicated that MST was correlated to ambient temperature, while LF/HF ratio was not found to be correlated at all. Heart rate was a little more correlate to low temperature than high temperature. The conclusions are significant to select suitable parameters for human thermal response research in the moderate thermal environment.

Keywords Physiological parameter · Moderate thermal environment · Sedentary activity · Correlation

1 Introduction

In order to research the indoor thermal comfort, multiple efforts are being devoted to investigating physiological parameters and their relationship with thermal sensation or ambient temperature conditions. Currently, the following physiological parameters are tested as objective indexes for human thermal response. Mean skin temperature (MST) is often measured as an essential physiological parameter related to thermal comfort [3]. Bin et al. [1] found that under the influence of high indoor velocity, MST would diverge from the thermal sensation. In that condition, heart rate variability (HRV) could reflect the human ability of thermal regulation. Choi et al. [2] reported that high metabolic rate would increase the volume of circulating blood, thus leading to an improvement in heart rate. Therefore, the heart rate has a significant relationship with metabolic rate and is usually tested in

L. Wang (✉) · Z. Chen · M. Chen
College of Urban Planning & Municipal Engineering, Xi'an Polytechnic University,
Xi'an 710048, China
e-mail: wljxpu@163.com

© Springer Nature Singapore Pte Ltd. 2020
Z. Wang et al. (eds.), *Proceedings of the 11th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC 2019)*, Environmental Science and Engineering, https://doi.org/10.1007/978-981-13-9520-8_1

different thermal environments [4]. These studies identified the potential of heart rate and heart rate variations as indicators for estimating the thermal comfort of human subjects. However, some other studies did not identify the significant relationship [6, 9]. Therefore, evaluation of the physiological parameters which are correlated to ambient temperature and which have the potential of indicating the human thermal response is highly desirable.

In this paper, MST, heart rate, the ratio of absolute power in low frequency (LF) and high frequency (HF) bands (LF/HF ratio) are selected. The correlation of these parameters toward moderate thermal environment was explored by conducting an analysis of variance (ANOVA) and R tests.

2 Methodology

2.1 Test Site

Human subject experiments were conducted in an office. The test site, with the dimension of $6.5 \times 2.5 \times 3.4 \text{ m}^3$ is located in Xi'an Polytechnic University. The office was equipped with a table, a chair, a bookshelf, a computer, and an air conditioning system. During the experiment, the door was kept closed.

2.2 Characteristics of Subject

Human beings at different ages have different thermal responses to the environment. Thus their physiological responses could be interfered by ages. In order to expel this disruptive factor, 17 young people (nine males and eight females) in the university were recruited as subjects. All the subjects were between the age of 22 and 25 years. Their height, weight, and age are listed in Table 1.

Subjects who might suffer from a skin disease, fever, and disorders, or might be using skin medicinal products that are known to interfere with the evaluation of skin physiology were excluded. The subjects were briefed on the procedure of this experiment, and informed consent was obtained from each participant. They were also prohibited from performing strenuous exercise, drinking coffee, or drinking alcoholic beverages 24 h prior to testing. The local skin which was attached to the

Table 1 Information about the subjects participating in this experiment

	Male	Female
Number	9	8
Age (years)	23.4 ± 1.6	23.3 ± 1.9
Height (m)	1.750 ± 0.056	1.624 ± 0.057
Weight (kg)	70.0 ± 7.4	54.1 ± 4.5

sensor was cleaned using alcohol. The subjects were required to be in the same type of clothes. Men wore T-shirts, short trousers, briefs, and sandal, while women wore T-shirts, short trousers, female briefs, sandal, and bra. The total clothing thermal resistances for both men and women were 0.32 clo.

2.3 Experimental Procedure

The experiment was carried out in summer, from July 1st to 27th. In consideration of the acceptance level of subjects, the ambient temperature should neither be too high nor too low. Therefore, the experimental condition was limited to the moderate thermal environment. Subjects were required to have meals and the experiment could not be completed in a short period; therefore, the air temperature was divided into two groups. One was controlled from 26 to 29 °C, the other was operated from 24 to 21 °C and the temperature increment for each group was 1 °C. The first half an hour was used for stabilization, and the last half an hour was used for testing. For each set temperature from 26 to 29 °C, the experiment was performed eight times with eight different subjects, while for each temperature from 24 to 21 °C, the experiment was conducted nine times with nine remaining subjects. The calculated operative temperature, tested air speed (v), and relative humidity (RH) are listed in Table 2.

2.4 Test Items and Instrumentation

The air temperature, globe temperature, air speed, and RH in the test field were measured using a thermal comfort meter MI6401. The location of measurements was in the occupied zone. According to ASHRAE 55. Human skin temperature includes LST and MST. LST refers to the skin temperature in the hand, arm, face, trunk, thigh, leg and foot. It can be measured directly by using an instrument. MST

Table 2 Environmental parameters in the experiment

Group	t_0 (°C)	Time (h)	v (m s ⁻¹)	RH (%)
1 (Increasing order of temperature)	26 ± 0.80	1	<0.1	51 ± 3.86
	27 ± 0.45	2		
	28 ± 0.66	3		
	29 ± 0.51	4		
2 (Decreasing order of temperature)	24 ± 0.67	1	<0.1	47 ± 4.6
	23 ± 0.75	2		
	22 ± 0.70	3		
	21 ± 0.79	4		