第600次学术讨论会·生物气溶胶与人类健康、国家生物安全及大气污染

空调通风系统对室内微生物气溶胶的影响

武艳^{1*}, 荣嘉惠¹, Irvan Luhung²

1. 山东大学环境科学与工程学院, 济南 250100;

2. SinBerBEST Program, Berkeley Education Alliance for Research in Singapore (BEARS), Singapore

* 联系人, E-mail: wuyan@sdu.edu.cn

2017-10-24 收稿, 2018-01-25 修回, 2018-01-29 接受, 2018-03-28 网络版发表

国家自然科学基金(41705126)和山东大学基本科研业务费专项资金(11440076614093)资助

摘要 现代建筑中的空调通风系统不可避免地接触输送到室内环境的空气, 而该系统对微生物空气质量的影响直接关系到室内人员的健康. 本文通过对大量的相关文献进行总结与归纳, 将空调通风系统对微生物气溶胶的影响分为两种: 一是空调通风系统的主要组分对微生物气溶胶的影响, 具体指其组分直接降低或者增加室内微生物气溶胶的浓度; 另一个是空调通风系统在运行过程中对室内微生物气溶胶的影响, 既包括通风率、气流组织等参数对微生物气溶胶的影响, 也包括该系统作为一条通道可将空气中已有的微生物从某一室内环境扩散到更多的室内环境. 另外, 本文通过分析空调通风系统污染室内空气的条件(如组分周围的物理和化学环境条件), 提出相应的控制措施, 如定期清理过滤器和通风管道等组分、及时去除热交换器和加湿器上的水分等, 可以减少空调通风系统引起的微生物污染, 从而保护室内人员的健康.

关键词 过滤器, 通风管道, 热交换器, 冷却塔, 微生物气溶胶

在现代建筑中, 空调通风系统(air conditioning and mechanical ventilation (ACMV) systems)主要包括新风口、送排风机、过滤器、通风管道、热交换盘管等, 可以控制和调节室内空气的温度、湿度等^[1~3], 提供新鲜干净的空气并去除室内污染物, 为人们创造舒适的、健康的室内环境^[4~6]. 一方面, 送往室内环境的空气不可避免地会与空调通风系统接触, 而二者之间的接触有可能改变空气的原有组成^[7~10]. 另一方面, 空调通风系统的正常运行也可能改变室内空气的组成, 不管是运行本身, 还是ACMV的参数设定^[11~15]. 前者主要指的是ACMV系统的不同组分本身对室内空气产生了直接影响, 比如ACMV直接向室内空气释放了一些化学污染物(如挥发性有机化合物(VOC))^[2~4, 16, 17]、颗粒物^[18~20]、微生物(如细菌和真菌)^[4~6, 21~24]; 后者既包括通风率、气流组织等参数对

室内空气的影响, 也包括该系统整体作为一条通道可将空气中已有的污染物(如致病菌)从某一室内环境扩散到更多的室内环境, 引起范围更广的室内人员的健康问题, 如结核杆菌通过通风系统扩散到室内环境引起多人感染肺结核^[13~16].

人们平均80%以上的时间处于室内环境, 空调通风系统对空气尤其是微生物空气方面的影响, 直接关系到我们的身体健康和工作效率^[17, 22, 25, 26]. 近年来, 很多研究指出病态建筑综合征(sick building syndrome, SBS)、哮喘、建筑相关疾病的反复出现均与室内微生物气溶胶暴露有关^[27~29]. 微生物气溶胶主要指动力学直径在100 μm 以内的悬浮于空气中的细菌、真菌和病毒等微生物和一些微生物碎片等, 广泛地分布于不同环境^[30~32]. Catrine等人^[33]发现空调通风管内的真菌可以释放到室内空气中, 并引起室

引用格式: 武艳, 荣嘉惠, Luhung I. 空调通风系统对室内微生物气溶胶的影响. 科学通报, 2018, 63: 920~930

Wu Y, Rong J H, Luhung I. Influence of air conditioning and mechanical ventilation (ACMV) systems on indoor microbial aerosols (in Chinese). Chin Sci Bull, 2018, 63: 920~930, doi: 10.1360/N972017-01114

内人员的眼睛不适。Björnsson等人^[34]发现室内空气中的细菌浓度和哮喘具有一定的相关性。同样, Ross等人^[35]也发现了随着室内空气中的革兰氏阴性菌和真菌孢子浓度增加, 室内哮喘患者的病情也随之加重。此外, Mentese和Tasdibi^[36]还发现了室内细菌的浓度水平和SBS的发生成正相关。除了细菌和真菌气溶胶外, 病毒气溶胶也是一种主要的微生物气溶胶, 多项研究发现室内空气中的病毒颗粒可以通过ACMV系统进行传播导致更多的人员患病。其中比较著名的是2003年的严重急性呼吸综合征(SARS)病毒被证实可通过ACMV传播^[25,37-39]。这些病毒通过空气传播, 可导致大范围的人员患病甚至死亡^[40]。因此, 开展空调通风系统对微生物气溶胶的影响研究, 可从建筑管理方面提出改善室内空气质量、降低健康风险的有效措施^[41-43]。下面就ACMV主要组分及运行对室内微生物气溶胶的直接影响、以及ACMV对致病菌的空气扩散的协助作用及相关科学问题作一介绍。

1 ACMV的主要组分对室内微生物气溶胶的影响

ACMV系统的组成部分对室内微生物气溶胶的直接影响分为两大类: 一是ACMV的主要组成, 可以作为微生物气溶胶的“采样器”或者“洗涤槽”, 去除空气中原有的微生物成分, 降低微生物污染, 进而提高室内空气质量^[44-47]; 另一个是ACMV系统的主要部分, 可以作为潜在的污染源, 释放微生物到该组分的下游空气, 提高空气中的微生物浓度, 污染室内环境, 并可能造成负面的健康影响^[2-4,48-50]。这些ACMV主要成分包括过滤器、通风管道、热交换器、冷却塔和加湿器等。下面详细介绍各个组分对室内微生物气溶胶的影响。

1.1 新风口的位置

一般来讲, 空调通风系统的新风口可以设在室内或者室外。根据《公共场所集中空调通风系统卫生规范》(2006年), 室内新风口底部与地面的距离需高于2 m; 室外新风口需设置在常年主导风向的上风侧。空调通风系统新风口位置如果设计安装不规范, 易导致室内空气污染。据调查报告统计, 室内与室外的新风口对空调通风系统送风口处空气中的细菌和真菌浓度有显著影响^[51-53]。赵岩等人^[53]发现新风口位

于室内时空调风管处的细菌和真菌浓度分布是新风口位于室外时的5倍和3倍。并且, 新风口与建筑物主要污染物排出口(如餐厅的排气口)之间的距离, 与空调通风管道内的可吸入颗粒物、沉降在管道上的微生物气溶胶之间存在正相关^[51]。因此, 适当的选择新风口的位置, 可有助于保证室内空气质量。

1.2 过滤器

ACMVs一般有两个过滤器, 一个是粗效过滤器(用来处理室外空气), 另一个是高效过滤器(一般是MERV-8过滤器, 处理室外空气和室内回风的混合气)^[44-46,54-57]。ACMV利用粗效过滤器处理室外空气得到室内环境需要的新风。这种粗效过滤器的效率不高, 无法完全去除室外空气中的微生物(尤其是真菌), 使得这些微生物进入ACMV的下游系统。一般来讲, ACMV系统的高效过滤器可以去除空气中的微生物气溶胶, 并将这些微生物保留在表面, 保障健康舒适的室内环境^[57-59]。Möritz等人^[44]发现新的ACMV过滤器可以有效地去除室外空气中的细菌和真菌, 去除效率分别为70%和80%, 但是这种去除效果需要较低的相对湿度和较高的温度。Noris等人^[45]发现在ACMV过滤器尘土上的细菌浓度在 $10^4 \sim 10^7$ CFU/g, 真菌浓度在 $10^3 \sim 10^7$ CFU/g, 证明过滤器是一种高效的微生物气溶胶采样器。而且, 他们也发现过滤器上的微生物种群结构和室内空气的一致, 证明过滤器本身可以作为室内空气微生物污染的一个可行的参照物。最新的一项研究利用DNA荧光测定法、定量基因扩增荧光检测系统(quantitative polymerase chain reaction, qPCR)和高通量测序表征过滤器上的微生物群落, 揭示了在大学中不同室内环境过滤膜上获取的微生物量和多样性信息^[46]。该研究发现, 新过滤器使用12周后, 9个室内环境的过滤器累积DNA为 $1.1 \sim 41$ ng/cm², 细菌DNA为 $0.02 \sim 3.3$ ng/cm², 真菌DNA为 $0.2 \sim 2.0$ ng/cm²。在ACMV过滤膜上检测到的丰度最高的细菌菌属是梭菌属、木霉菌属、芽孢杆菌、不动杆菌属和纤维杆菌属, 真菌菌属是曲霉属真菌、芽枝霉属、黑孢属、硬孔菌属和香菇属。此外, 该研究还揭示了空气中细菌DNA相较于对真菌DNA更易受室内人数和室内环境条件的影响^[46]。

但是, 当湿度保持长时间较高并且过滤器使用了一定时间后, 下游空气中的细菌和真菌浓度明显高于上游空气, 过滤器成为了室内微生物气溶胶的

一个来源^[44,58-61]. 这是因为在实际操作中, 由于新风净化不足或者由于过滤器的更换和清理不当等原因, 很多微生物气溶胶沉降在过滤器后, 利用过滤器上收集的尘土中的营养物质进行自我复制, 生成更多的微生物^[58-60]. 并且, 过滤器上的尘土含量和微生物的浓度呈正相关, 尘土含量越高, 细菌和真菌的浓度也越高^[61-64]. 而且, 这些微生物的粒径一般小于10 μm , 容易被人体吸入^[44]. 在气流的扰动下, 过滤膜上的微生物可以气溶胶化进入空气, 并随气流进入到下游空气, 可能最终进入室内环境^[4,9,65-67]. 除了湿度和过滤器上的尘土外, 过滤器的分类、材料和通过过滤器的风速等因素也可影响过滤器上的微生物的生长^[9,58-60]. 为了减少过滤膜的微生物污染和提高去除效率, 很多研究往往在过滤器上添加抑菌剂, 或者与其他物理化学方法联用^[62,68,69]. Han等人^[62]在过滤膜上添加葡萄柚种子提取物作为抑菌剂, 可以有效灭活ACMV过滤器采集的微生物. Huang等人^[63]通过释放单极空气离子(unipolar air ions), 可以显著地提高过滤器对细菌和真菌的去除效率, 尤其是细菌的去除效率可增加4~5倍. Noh等人^[64]利用碳纤维离子发生器同样可以增强通风系统过滤器的过滤效率, 对亚微米颗粒物的去除效率提高了10%~25%. 在最新的一项研究中, Ng等人^[66]利用声波团聚(acoustic agglomeration)的方法, 可以在不增加过滤器压力的前提下将过滤器的去除效率增加10%, 既能减少能耗又能提高室内微生物空气质量. 当然, 及时清理或者更换过滤器也是一种有效防止微生物污染的办法, 同时也能节约能耗^[70-72].

尽管长时间以来, 很多研究开展了过滤器对微生物气溶胶的影响研究, 但目前过滤器相关研究还存在几个问题仍需解决: (1) 过滤器的效率随着颗粒物的积聚而变化, 因此, 在过滤器使用期间, 微生物气溶胶可能以可变的速率在过滤器上累积, 从而导致定量分析微生物累积量比较困难; (2) 同一个过滤器上的微生物的含量和种类存在分布不均的问题, 这就使得分析结果出现很大的误差; (3) 微生物造成污染所需的环境条件和过滤膜条件有待进一步研究; (4) 微生物活性的保持, 在采样分析之前, 过滤器上的微生物可能失活, 也有可能微生物已经完成了自我复制, 我们无法得知在采样之前这些微生物的状态, 也无法客观地评估过滤器对微生物细胞完整性和活性的影响, 今后的研究可以围绕这些问题开展.

1.3 通风管道

通风管道也是ACMVs不可缺少的部分, 目的是使空气在管道内充分混合并将空气输送到室内环境^[73-75]. 由于通风管道可以使用很长时间, 加上管道的表面积巨大(约室内面积的10%), 微生物在管道内的行为对室内空气质量有着重要影响^[75-77]. 一方面, 通风管道可以看作空气颗粒物的“采样器”, 因为足够长的管道可以使微生物气溶胶沉降在其表面, 尤其对粒径大于5 μm 的颗粒有很好的采集效率^[78-80]. ACMV管道中细菌的浓度高达 4.0×10^5 CFU/cm², 真菌的浓度比细菌低很多, 一般在1000 CFU/cm²以下^[79-81]. 另一方面, 通风管道也可作为微生物进行繁殖的场所, 沉降在管道上的细菌和真菌可利用沉降在管道上的其他颗粒物(尘土形式)为营养进行繁殖^[81-84]. 而且, 管道内的风速、温度、管道长度、管道的材料和制作过程、管道表面上沉积的颗粒物(尘土)、相对湿度和过滤器的效率等因素均影响管道对微生物的作用(去除或者增加)^[9,82-85]. 一项研究开展了ACMV运行参数对管道上的微生物生长的影响, 发现在温度22~32 $^{\circ}\text{C}$, 相对湿度40%~90%的范围内, 细菌和真菌有着明显的生长现象^[79]. 而且, 在这个范围内, 随着温度和湿度的升高, 微生物的繁殖速度明显加快. 在另一项实验室研究中, Chang等人^[81]在3种新的ACMV管道上培养真菌*P. chrysogenum*, 发现加上实际ACMV管道中的尘土后, 3种管道上均出现了真菌的生长繁殖现象. 这些研究都证明了ACMV管道尘土中的物质可以给微生物生长提供营养. Anna-Liisa等人^[82]分析了管道尘土样品中的真菌种类, 发现主要的真菌有芽枝霉属、青霉菌属、曲霉属和酵母菌, 其中孢子浓度高达 10^8 个/g. 另外, ACMV通风管道上的细菌、真菌孢子和真菌释放的挥发性有机化合物, 均有可能排放到空气中, 并随气流进入室内环境, 降低室内空气质量, 并可引起负面健康影响^[84-87]. 因此, 及时清扫通风管道或者结合物理化学方法(如紫外线), 可以减少微生物的污染, 间接降低室内微生物气溶胶的浓度^[84-87].

1.4 热交换器

ACMV系统的热交换器主要用来空气制冷或者制热. 很多研究也指出, 空气中的颗粒物和微生物可以沉降在热交换盘管的表面, 并且颗粒物的粒径越大, 其在热交换盘管的沉积率越高^[18-20,47,76,88-91].

Siegel等人^[18-20]利用模型模拟颗粒物不同条件下的沉降研究,发现湿交换盘管相比于干交换盘管具有更高的空气净化效率,可以去除空气中高达65%的颗粒物。而且,ACMV系统内风速的提高也会增加颗粒物包括微生物颗粒物在热交换盘管上的沉降,也就是提高热交换盘管的空气净化效率。在最新的一项研究中,Wu等人^[47]发现在每千克干空气中有36 pg的总DNA,45 fg的细菌DNA和189 fg的真菌DNA可以沉降在湿的热交换盘管上。如果以大肠杆菌细胞为标准进行估算,那么工作9 h的ACMV系统约有10万个细菌可沉降在的热交换盘管的表面^[92]。和过滤器一样,当空气的湿度较高的情况下,一些有活性的微生物可利用其他物质为营养物质进行自我复制,这些微生物还可能随着气流进入室内空气^[90-92]。有研究发现图书馆热交换盘管下游空气中的细菌浓度是上游的10倍,并且这些细菌中大部分有活性^[91]。同样,在其他研究中发现,空调打开后室内的微生物气溶胶的浓度会立刻显著增加^[93-95]。Schmidt等人^[96]发现在普通的铝制热交换盘管表面上,细菌浓度为11411~47257 CFU/cm²,真菌平均浓度为378 CFU/cm²,而铜制的热交换盘管上细菌和真菌的浓度均小于3 CFU/cm²,结果显示盘管的材料可以影响微生物的种类和浓度。他们还发现该热交换盘管使用4周后,该热交换盘管表面可以形成稳定的微生物膜,而且每平方厘米膜上的微生物细胞数超过了47000^[96]。Acerbi等人^[97]跟踪分析了新的制冷交换器使用17 d的情况,不仅在交换器表面可以检测到大量的具有活性的细菌(如鞘氨醇单胞菌和甲基杆菌属)和真菌(如伞菌纲),还证明了其中部分微生物是可以利用热交换盘管表面上的物质进行自我繁殖。这些研究都揭示了热交换盘管表面可作为微生物繁殖的场所^[93-97]。

总的来说,新的或者维护合理的空调热交换盘管可以有助于从气流中去除微生物气溶胶,从而有助于降低室内空气中这些微生物的浓度,相应地降低人体暴露风险。单从这个角度讲,热交换器上的沉积可被认为是一个很好的现象。然而,热交换盘管表面上的积聚的水分和颗粒物也可为微生物生长提供良好的条件,当微生物在其表面上形成微生物膜后可导致以下后续问题:(1)增加能耗,这是因为热交换盘管上沉积的微生物可以降低热传递效率;(2)沉降的微生物以及微生物的代谢、繁殖与细胞产物等,有可能释放到下游空气,造成二次污染^[9,95-97]。在实

际操作中,我们建议及时清洁热交换盘管和去除表面上的水分,降低微生物的繁殖。

另外,ACMV在制冷的时候,由于热交换会产生很多冷凝水,这些冷凝水一般由冷凝器收集并排放。在实际操作中,由于凝水管坡度不够,或有很大的存水弯,抑或被灰尘堵塞,容易造成冷凝水的积聚。含冷凝水的冷凝器可以在系统停用期间为细菌和真菌的繁殖提供良好的环境^[9-11,91,98,99]。尤其是冷凝水中还有从空气中冲刷下来的其他颗粒物,这些颗粒物可以为微生物的繁殖提供良好的营养条件。Hugenholz和Fuerst^[91]在冷凝水盘中发现细菌的浓度高达 6.3×10^7 CFU/mL,而芽生杆菌属、黄杆菌属和假单胞菌属是主要的细菌。在我国北京某写字楼发生了由空调系统导致的上呼吸道感染,经验证是军团菌污染的冷凝水气溶胶化被气流带到了室内环境,通过呼吸暴露引起室内人员感染疾病^[92]。在另一项研究中,Acerbi等人^[97]分析了新的制冷交换器使用时产生的冷凝水样品,发现在17 d内,细菌鞘氨醇单胞菌在总微生物中的相对丰度明显升高,从开始的5%迅速提升到30%,而真菌银耳纲菌属则从低于检测线升到11%。Wu等人^[47]在每小时收集到的冷凝水中也发现了大量的DNA,其中总DNA的浓度为10~13 ng/L,细菌和真菌的DNA浓度在0.01~0.3 ng/L。值得一提的是,每天的冷凝水中总DNA和微生物DNA浓度呈现不同的时间趋势:总DNA的浓度比较稳定,一直维持在10~13 ng/L;而微生物的DNA浓度有明显的下降趋势,且在第1个小时浓度为当日的峰值^[47]。但是,当前仍缺乏关于ACMV的操作模式、冷凝水的温度和pH等如何影响冷凝水中微生物的含量和活性的研究。

1.5 冷却塔

冷却塔主要用来降低水温。很多研究指出,冷却塔可以作为微生物复制的场所,而且这些微生物在一定条件下可气溶胶化并通过ACMV系统进入室内环境,成为是室内微生物气溶胶,并通过呼吸暴露引起负面健康效应^[100-103]。众所周知,美国多次发生的军团病事件就是冷却塔水中的强致病菌军团菌气溶胶化通过ACMV系统进入室内引发多人死亡^[102]。在日本,49个医院的冷却塔中有39个检测到了具有活性的军团菌,浓度从10~105 CFU/100 mL^[103]。我国公共场所ACMV的冷却塔的情况也并不乐观,如大连市ACMV冷却水嗜肺军团菌的检出率为27.3%^[87],而上

海市大型公共场所集中空调冷却水嗜肺军团菌的检出率43.7%^[104].

1.6 加湿器

加湿器在空调通风系统中有着广泛应用,其作用是增加空气中的湿度,以提高室内人员的舒适性^[105,106].但是,空调加湿器也是细菌、真菌、病毒等微生物繁殖的重要场所,通向室内的气流可以雾化加湿器表面上的微生物,生成微生物气溶胶,并在气流的带动下进入室内环境,降低室内空气品质.但是目前关于空调加湿器的研究还集中于改善加湿性能方面,如通过设计合理的吸收距离和水雾粒径等来提高加湿性能,仍缺少空调加湿器对微生物气溶胶的影响研究.

总的来说,对可以影响室内微生物气溶胶的ACMV的主要组分,目前已经开展了相关研究,分析了ACMV组分净化或者污染室内空气的影响因素,这些因素主要包括3个方面:(1) 组分自身的因素,比如该组分的材料和设计;(2) 组分周围的物理和化学环境条件,如湿度、温度和气流等;(3) 组分的运行与维护问题.

2 ACMV运行对室内微生物气溶胶的影响

除了上文提到的组分之外,ACMV的运行参数和方式等(如通风率和管道内的气流组织形式)也可对微生物气溶胶产生影响.

2.1 通风率

通风率主要是指多少比例的室外空气可以进入室内,即每小时室内空气完全更新的次数.很多研究指出通风率对室内人员的健康有重要的影响^[107~110].Menzies等人^[107]发现在医院结核病房里的通风率小于2次/h时,医院工作人员被结核杆菌感染的几率增加.Hoge等人^[108]发现在监狱里,低的通风率和肺炎的爆发有直接关系.Myatt等人^[109]发现当室内二氧化碳的浓度高于1000 ppm(1 ppm=1 mg/L),即室内通风率非常低的时候,室内空气中可以检测到高浓度的鼻病毒DNA及其片段.为了室内人员的健康,尤其是预防和微生物气溶胶相关的疾病,很多国际组织建议室内(如学校和医院)的通风率应在2~15次/h,但是目前仍然缺少确切的证据证明这些规定的必要性.

2.2 气流组织

气流组织形式主要有散流器上送风、格栅风口、侧送风以及侧墙置换送风等^[110,111].有研究指出,当通风率小于3次/h时,气流组织为侧送底排时细菌气溶胶的浓度明显高于侧送顶排和侧送侧排时的细菌气溶胶浓度^[110].而且,当通风率小于1.5次/h时,气流组织为侧送侧排时的细菌气溶胶的浓度明显高于侧送顶排时的细菌气溶胶浓度;当通风率在1.5~3次/h时,气流组织为侧送侧排时的细菌气溶胶的浓度明显低于侧送顶排时的细菌气溶胶浓度.不同于细菌气溶胶,当通风率在0~3次/h时,真菌气溶胶的浓度在气流组织为侧送顶排时达到最高.而且,不同的气流组织下细菌气溶胶的浓度高于真菌气溶胶的浓度.总的来说,气流组织对室内微生物气溶胶的分布具有很大的影响,并且该影响与微生物气溶胶的种类、通风率等有关^[110,111].

2.3 ACMV的“通道效应”

ACMV的功能是向室内环境输送空气,其中全部或者大部分是循环的室内空气,如果室内空气被某种污染物污染了,这个污染物可以通过ACMV系统扩散到更多的室内环境,引起范围更广的室内人员的健康问题^[12~16,25,40,107~109].多项研究发现,结核杆菌、风疹、水痘、感冒病毒、天花和SARS等均可通过通风系统从一个室内环境扩散到其他室内环境,引起多人感染疾病^[12~16,107~109].Li等人^[25]发现SARS病毒是通过ACMV传播到其他室内环境的,这种将ACMV作为“绿色通道”的传播导致了更多的患者.Yu等人^[40]同样证实了SARS病毒可以通过ACMV的正常运行传播到了更多的室内环境.除了一般的建筑环境外,特殊室内环境中(如医院、监狱和船)也发现了类似的传播^[14,107,108].Houk^[14]发现在一海军舰艇上结核杆菌通过空调系统导致308船员感染疾病.Menzies等人^[107]在医院里发现结核杆菌可以通过空调系统传播,而Hoge等人^[108]发现监狱里肺炎链球菌亦通过空调系统传播到更多的室内环境.这些病原体依靠ACMV的正常运行被从一个室内环境输送到了其他室内环境,从而引起了较大规模的人员患病.

3 结论

总的来说,设计合理的、维护适当的ACMV系统可以有效地去除空气中的微生物,可以给我们创造

舒适的、健康的室内空气。而且,对于正在使用的ACMV系统,通过控制ACMV系统的相对湿度,选择合适的通风率,及时清理过滤器、通风管道和其他组分,及时去除冷却盘和热交换器上的水分等,可以减少ACMV的微生物污染,降低空气中的微生物含量,进而保护室内人员的健康。但是在实际环境中,由于维护不当或者其他原因,很多ACMV系统给微生物的生存提供了有利条件,我们需要根据建筑和空调通风系统本身,结合地区性大气环境,对室内微生物污染进行综合控制。而且,在ACMV系统对室内微生物气溶胶影响方面,目前仍有以下几个方面有待研

究:(1)ACMV作为一个整体对室内微生物气溶胶的影响以及各个组分的相对增加仍不明确;(2)ACMV主要组分对微生物气溶胶的去除或者贡献作用的临界条件仍不明确,尤其是不同地区不同建筑之间存在巨大差异;(3)目前的研究主要集中分析微生物的种群结构和活性,并没有进一步开展微生物的产物如内毒素和过敏原在ACMV主要组分上的动态行为。

在今后的工作中,继续深入开展空调通风系统对室内微生物气溶胶的影响研究,可从建筑管理方面提出改善室内空气质量、降低空调通风系统对人体健康和工作效率的不良影响。

参考文献

- 1 Afram A, Janabi S F. Theory and applications of ACMV control systems—A review of model predictive control (MPC). *Build Environ*, 2014, 72: 343–355
- 2 Pérez L L, Ortiz J, Coronel J F, et al. A review of ACMV systems requirements in building energy regulations. *Energy Build*, 2011, 43: 255–268
- 3 Fisk W J. Health and productivity gains from better indoor environments and their relationship with building energy efficiency. *Annu Rev Energy Environ*, 2000, 25: 537–566
- 4 Bluysen P M, Cox C, Seppänen O, et al. Why, when and how do ACMV-systems pollute the indoor environment and what to do about it? *Build Environ*, 2003, 38: 209–225
- 5 Bitter F, Fitzner K. Odour emissions from an ACMV-system. *Energy Build*, 2002, 34: 809–816
- 6 Seppänen O. Ventilation strategies for good indoor air quality and energy efficiency. *Int J Vent*, 2008, 6: 297–306
- 7 Montgomery J F, Green S I, Rogak S N, et al. Predicting the energy use and operation cost of ACMV air filters. *Energy Build*, 2012, 47: 643–650
- 8 Choi J H, Loftness V, Aziz A. Post-occupancy evaluation of 20 office buildings as basis for future IEQ standards and guidelines. *Energy Build*, 2012, 46: 167–175
- 9 Bluysen P M, Cox C, Souto J, et al. Pollution from filters, what is the reason, how to measure and to prevent it? *Health Build*, 2000, 2: 251–256
- 10 Bonetta S, Bonetta S, Mosso S, et al. Assessment of microbiological indoor air quality in an Italian office building equipped with an ACMV system. *Environ Monit Assess*, 2010, 161: 473–483
- 11 Batterman S A, Burge H. ACMV systems as emission sources affecting indoor air quality: A critical review. *ACMV&R Res*, 1995, 1: 61–80
- 12 Yu B F, Hu Z B, Liu M, et al. Review of research on air-conditioning systems and indoor air quality control for human health. *Int J Refrig*, 2009, 32: 3–20
- 13 Li Y, Leung G, Tang M, et al. Role of ventilation in airborne transmission of infectious agents in the built environment—A multidisciplinary systematic review. *Indoor Air*, 2007, 17: 2–18
- 14 Houk V N. Spread of tuberculosis via recirculated air in a vessel. *Ann N Y Acad Sci*, 1980, 353: 10–24
- 15 Croft W A, Jarvis B B, Yatawara C S. Airborne outbreak of trichothecene toxicosis. *Atmos Environ*, 1986, 20: 549–552
- 16 Yang X, Srebric J, Li X, et al. Performance of three air distribution systems in VOC removal from an area source. *Build Environ*, 2004, 39: 1289–1299
- 17 Xiao D T, Shi F E. Microbial aerosol pollution in ventilation and air conditioning systems: Prevention and control (in Chinese). *Environ Sci Technol*, 2017, 8: 139–152 [肖栋天, 石发恩. 通风空调环境中微生物气溶胶污染及其防治. *环境科学与技术*, 2017, 8: 139–152]
- 18 Siegel J A. Particulate fouling of ACMV heat exchangers. Doctoral Dissertation. Berkeley: University of California, 2002
- 19 Siegel J, Carey V P. Fouling of ACMV fin and tube heat exchangers. Report LBNL-47668, Berkeley, California: Lawrence Berkeley National Laboratory, 2001
- 20 Siegel J A, Nazaroff W W. Predicting particle deposition on ACMV heat exchangers. *Atmos Environ*, 2003, 37: 5587–5596

- 21 Pasanen A, Heinonen T H, Kalliokoski P, et al. Fungal microcolonies on indoor surfaces—An explanation for the base-level fungal spore counts in indoor air. *Atmos Environ*, 1992, 26B: 117–120
- 22 Wyon D P. The effects of indoor air quality on performance and productivity. *Indoor Air*, 2004, 14: 92–101
- 23 Pasanen A L, Pasanen P, Jantunen M J, et al. Significance of air humidity and air velocity for fungal spore release into the air. *Atmos Environ*, 1991, 25A: 459–462
- 24 Simmons R B, Crow S A. Fungal colonization of air filters for use in heating, ventilating, and air conditioning (ACMV) systems. *J Ind Microbiol*, 1995, 14: 41–45
- 25 Li Y, Huang X, Yu I T S, et al. Role of air distribution in SARS transmission during the largest nosocomial outbreak in Hong Kong. *Indoor Air*, 2005, 15: 83–95
- 26 Beggs C B. The airborne transmission of infection in hospital buildings: Fact or fiction? *Indoor Built Environ*, 2003, 12: 1–10
- 27 Daisey J M, Angell W J, Apte M G. Indoor air quality, ventilation and health symptoms in schools, an analysis of existing information. *Indoor Air*, 2003, 13: 53–64
- 28 Fennelly K P, Nardell E A. The relative efficacy of respirators and room ventilation in preventing occupational tuberculosis. *Infect Control Hosp Epidemiol*, 1998, 19: 754–759
- 29 Tandon P S, Saelens B E, Zhou C, et al. Indoor versus outdoor time in preschoolers at child care. *Am J Prev Med*, 2013, 44: 85–88
- 30 Che F X. Bioaerosol and human diseases (in Chinese). *Chin J Health Lab Technol*, 1997, 7: 252–256 [车凤翔. 生物气溶胶与人体疾病. *中国卫生检验杂志*, 1997, 7: 252–256]
- 31 Chai T J, Zhang J X, Hou Y P, et al. Spread of microorganism aerosol in animal house to its environments (in Chinese). *Anim Husbandary Vet Med*, 2001, 33: 10–12 [柴同杰, 张继祥, 侯颜平, 等. 畜禽舍微生物气溶胶向环境扩散的研究. *畜牧与兽医*, 2001, 33: 10–12]
- 32 Yu X H. The infection and control of microorganism aerosol: Concurrently treats of prevent in the SARS virus (in Chinese). *Contam Control Air-condition Technol*, 2003, (4): 25–29 [于玺华. 微生物气溶胶的感染与控制: 兼论 SARS 病毒预防. *洁净与空调技术*, 2003, (4): 25–29]
- 33 Catrine A, Hans T S, Dan N, et al. Sign of eye irritation in female hospital workers and the indoor environment. *Indoor Air*, 2001, 11: 223–231
- 34 Björnsson E, Norback D, Janson C, et al. Asthmatic symptoms and indoor levels of micro-organisms and house dust mites. *Clin Exp Allergy*, 1995, 25: 423–431
- 35 Ross M, Curtis L, Scheff P, et al. Association of asthma symptoms and severity with indoor bioaerosols. *Allergy*, 2000, 55: 705–711
- 36 Mentese S, Tasdibi D. Airborne bacteria levels in indoor urban environments: The influence of season and prevalence of sick building syndrome (SBS). *Indoor Built Environ*, 2014, 25: 563–580
- 37 Strausbaugh L J, Sukumar S R, Joseph C L. Infectious disease outbreaks in nursing homes: An unappreciated hazard for frail elderly persons. *Int J Refrig*, 2003, 36: 870
- 38 Du Q, Wen Z B, Li J S. Mechanism of viral aerosol and its droplet transmission and distribution in the indoor environment: A research progress (in Chinese). *Mil Med Sci*, 2011, 35: 631–633 [杜茜, 温占波, 李劲松. 病毒气溶胶飞沫在室内环境中传播扩散机制的研究进展. *军事医学*, 2011, 35: 631–633]
- 39 Xu Q, Fan Q Y, Duan N, et al. Air-borne spread pathway in intensive care unit (ICU) of specialized SARS Hospital (in Chinese). *Chin J Nosocomiol*, 2005, 15: 1380–1382 [徐潜, 范钦颖, 段宁, 等. 医院 SARS 重症监护病区空气传播途径的研究. *中华医院感染学杂志*, 2005, 15: 1380–1382]
- 40 Yu I T, Li Y, Wong T W, et al. Evidence of airborne transmission of the severe acute respiratory syndrome virus. *N Engl J Med*, 2004, 350: 1731–1739
- 41 Mendell M J, Smith A H. Consistent pattern of elevated symptoms in air-conditioned office buildings, a reanalysis of epidemiologic studies. *Am J Public Health*, 1990, 80: 1193–1199
- 42 Wargocki P, Wyon D P, Sundell J, et al. The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity. *Indoor Air*, 2000, 10: 222–236
- 43 Laumbach R J, Kipen H M. Bioaerosols and sick building syndrome, particles, inflammation, and allergy. *Curr Opin Allergy Clin Immunol*, 2005, 5: 135–139
- 44 Möritz M, Peters H, Nipko B, et al. Capability of air filters to retain airborne bacteria and molds in heating, ventilating and air-conditioning (ACMV) systems. *Int J Hyg Environ Health*, 2001, 203: 401–409
- 45 Noris F, Siegel J A, Kinney K A. Evaluation of ACMV filters as a sampling mechanism for indoor microbial communities. *Atmos Environ*, 2011, 45: 338–346
- 46 Luhung I, Wu Y, Xu S, et al. DNA accumulation on ventilation system filters in university buildings in Singapore. *PLoS One*, 2017, 12: e0186295
- 47 Wu Y, Chen A, Luhung I, et al. Bioaerosol deposition on an air-conditioning cooling coil. *Atmos Environ*, 2016, 144: 257–265

- 48 Haleem K A A, Mohan K S. Practices contributing to biotic pollution in air-conditioned indoor environments. *Aerobiologia*, 2011, 27: 85–89
- 49 Gupta S, Khare M, Goyal R. Sick building syndrome—A case study in a multistory centrally air-conditioned building in the Delhi City. *Build Environ*, 2007, 42: 2797–2809
- 50 Sundell J, Lindvall T, Stenberg B. Associations between type of ventilation and air flow rates in office buildings and the risk of SBS-symptoms among occupants. *Environ Int*, 1994, 20: 239–251
- 51 Li Y. Influence of fresh air outlet of centralized air conditioning and ventilation system on air quality (in Chinese). *Chin J PHM*, 2010, 26: 192–193 [李尧. 集中空调通风系统新风口位置对空气质量的影响. *中国公共卫生管理杂志*, 2010, 26: 192–193]
- 52 Xu W H, Han H. Effect of HVAC system on indoor air quality and improving countermeasure (in Chinese). *Shanghai Environ Sci*, 1999, 18: 208–210 [徐文华, 韩华. 空调系统对室内空气品质的影响及改进对策. *上海环境科学*, 1999, 18: 208–210]
- 53 Zhao Y, Feng L H, Yu L Q, et al. Hygienic situation and influencing factors for centralized air conditioning ventilation systems in Tianjin (in Chinese). *J Environ Health*, 2012, 29: 1120–1123 [赵岩, 冯利红, 于凌琪, 等. 天津市公共场所集中空调通风系统卫生状况及影响因素. *环境与健康杂志*, 2012, 29: 1120–1123]
- 54 Nygaard A B, Charnock C. The bacterial composition of ventilation filter dust in norwegian pre-school nurseries. *Indoor Built Environ*, 2017, doi: 10.1177/1420326X17713831
- 55 González L F, Joubert A, Andrès Y. Filtration performances of ACMV filters for PM₁₀ and microbial aerosols—Influence of management in a lab-scale air handling unit. *Aerosol Sci Technol*, 2016, 50: 555–567
- 56 Stanley N J, Kuehn T H, Kim S W, et al. Background culturable bacteria aerosol in two large public buildings using ACMV filters as long term, passive, high volume air samplers. *J Environ Monit*, 2008, 10: 474–481
- 57 Park J H, Yoon K Y, Hwang J. Removal of submicron particles using a carbon fiber ionizer-assisted medium air filter in a heating, ventilation, and air-conditioning (ACMV) system. *Build Environ*, 2011, 46: 1699–1708
- 58 Parat S, Fricker H H, Perdrix A, et al. Airborne fungal contamination in air-conditioning systems, effect of filter and humidifying devices. *Am Ind Hyg Assoc J*, 1996, 57: 996–1001
- 59 Ahearn D G, Crow S A, Simmons R B, et al. Fungal colonization of air filters and insulation in a multi-story office building, production of volatile organics. *Curr Microbiol*, 1997, 35: 305–308
- 60 Simmons R B, Price D L, Noble J A, et al. Fungal colonization of air filters from hospitals. *AIHA J*, 1997, 58: 900–904
- 61 Liu Z, Zhu Z, Zhu Y, et al. Investigation of dust loadings and culturable microorganisms of ACMV systems in 24 office buildings in Beijing. *Energy Build*, 2015, 103: 166–174
- 62 Han B, Kang J S, Kim H J. Investigation of antimicrobial activity of grapefruit seed extract and its application to air filters with comparison to propolis and shiitake. *Aerosol Air Qual Res*, 2015, 15: 1035–1044
- 63 Huang R, Agranovski I, Pyankov O, et al. Removal of viable bioaerosol particles with a low-efficiency ACMV filter enhanced by continuous emission of unipolar air ions. *Indoor Air*, 2008, 18: 106–112
- 64 Noh K C, Lee J H, Kim C, et al. Filtration of submicron aerosol particles using a carbon fiber ionizer-assisted electret filter. *Aerosol Air Qual Res*, 2011, 11: 811–821
- 65 Pyankov O V, Agranovski I E, Huang R, et al. Removal of biological aerosols by oil coated filters. *Clean*, 2010, 36: 609–614
- 66 Ng B F, Xiong J W, Wan M P. Application of acoustic agglomeration to enhance air filtration efficiency in air-conditioning and mechanical ventilation (ACMV) systems. *PLoS One*, 2017, 12: e0178851
- 67 Pigeot R S, Lazzaroni J C, Simonet F, et al. Survival of bioaerosols in ACMV system photocatalytic filters. *Appl Catal B*, 2014, 144: 654–664
- 68 Tringe S G, Zhang T, Liu X, et al. The airborne metagenome in an indoor urban environment. *PLoS One*, 2008, 3: e1862
- 69 Nie Y X, Shen J M, Qiu J F. A study on several test methods of antimicrobial filter media's bacteriostatic activity (in Chinese). *Build Energy Environ*, 2006, 25: 11–14 [聂一新, 沈晋明, 邱济夫. 抗菌空气过滤器滤料抑菌性能试验方法的研究. *建筑热能通风空调*, 2006, 25: 11–14]
- 70 Fisk W J. Health benefits of particle filtration. *Indoor Air*, 2013, 23: 357–368
- 71 Wilson E J H, McNeill J S, Zhai Z, et al. A parametric study of energy savings from cleaning coils and filters in constant air volume ACMV systems. *ACMV&R Res*, 2013, 19: 616–626
- 72 Waring M S, Siegel J A. Particle loading rates for ACMV filters, heat exchangers, and ducts. *Indoor Air*, 2008, 18: 209–224
- 73 Wang X C, Chen S J, Wu X H. Investigation of ventilation pipe pollution in central air conditioning systems of public places in Hangzhou (in Chinese). *Zhejiang Prev Med*, 2007, 19: 49–50 [王旭初, 陈士杰, 吴小辉. 杭州市公共场所集中式空调通风管道污染状况调查. *浙江预防医学*, 2007, 19: 49–50]
- 74 Sippola M R, Nazaroff W W. Modeling particle loss in ventilation ducts. *Atmos Environ*, 2003, 37: 5597–5609
- 75 Sippola M R, Nazaroff W. Experiments measuring particle deposition from fully developed turbulent flow in ventilation ducts. *Aerosol Sci Technol*, 2004, 38: 914–925

- 76 Zhao B, Wu J. Modeling particle deposition from fully developed turbulent flow in ventilation duct. *Atmos Environ*, 2006, 40: 457–466
- 77 Wu J, Zhao B. Effect of ventilation duct as a particle filter. *Build Environ*, 2007, 42: 2523–2529
- 78 Chen F N, Zhao B, Yang X D. Investigation and review of microbial pollution in air conditioning systems of public buildings (in Chinese). *J HV&AC*, 2009, 39: 50–56 [陈凤娜, 赵彬, 杨旭东. 公共场所空调通风系统微生物污染调查分析及综述. *暖通空调*, 2009, 39: 50–56]
- 79 Li A, Liu Z, Zhu X, et al. The effect of air-conditioning parameters and deposition dust on microbial growth in supply air ducts. *Energy Build*, 2010, 42: 449–454
- 80 Li A, Liu Z, Liu Y, et al. Experimental study on microorganism ecological distribution and contamination mechanism in supply air ducts. *Energy Build*, 2012, 47: 497–505
- 81 Chang J C S, Foarde, K K, Vanosdell D W. Assessment of fungal (*penicillium chrysogenum*), growth on three HVAC duct materials. *Environ Int*, 1996, 22: 425–431
- 82 Anna-Liisa P, Liisa K, Pertti P, et al. Culturable and total fungi in dust accumulated in air ducts in single-family houses. *Indoor Air*, 1997, 7: 121–127
- 83 Lu Z, Lu W Z, Zhang J L, et al. Microorganisms and dust in AHU systems, measurement and analysis. *Build Environ*, 2009, 44: 694–698
- 84 Sugawara F, Morooka N. Microbial contamination in ducts of air conditioning systems. *J Asian Archit Build*, 1997, 62: 55–60
- 85 Björkroth M, Asikainen V. The effect of ventilation duct material and dust accumulation on perceived supply air quality. *Health Build*, 2000, 2: 157–162
- 86 Björkroth M, Müller B, Küchen V, et al. Pollution from ducts, what is the reason, how to measure and how to prevent it? *Health Build*, 2000, 2: 163–168
- 87 Sun Y H, Zhang H X, Guo Q, et al. Hygienic situation of HVAC systems in 14 public places of Dalian (in Chinese). *Chin J Public Health Eng*, 2009, 8: 356–358 [孙亚慧, 张洪轩, 郭琦, 等. 大连市 14 家公共场所集中空调通风系统卫生学调查. *中国卫生工程学*, 2009, 8: 356–358]
- 88 Grigonyte J, Nuutinen I, Koponen T, et al. Evaluation of a heat exchanger designed for efficient fine particle precipitation in small-scale wood combustion. *Energy Fuels*, 2014, 28: 6058–6065
- 89 Zhan F, Zhuang D, Ding G, et al. Numerical model of particle deposition on fin surface of heat exchanger. *Int J Refrig*, 2016, 72: 27–40
- 90 Luongo J C, Miller S L. Ultraviolet germicidal coil cleaning, Decreased surface microbial loading and resuspension of cell clusters. *Build Environ*, 2016, 105: 50–55
- 91 Hugenholtz P, Fuerst J A. Heterotrophic bacteria in an air-handling system. *Appl Environ Microbiol*, 1992, 58: 3914–3920
- 92 Ma X Y, Wang Y Q, Peng X W, et al. Investigation of an Legionnaires' disease outbreak associated with contaminated air conditioning system (in Chinese). *Chin J Epidemiol*, 1998, 19: 200–204 [马小燕, 王玉琴, 彭晓文, 等. 一起空调系统导致上呼吸道感染样军团病爆发的调查. *中华流行病学杂志*, 1998, 19: 200–204]
- 93 Hamada N, Fujita T. Effect of air-conditioner on fungal contamination. *Atmos Environ*, 2002, 36: 5443–5448
- 94 Abe K. Fungal index and contamination in air conditioners when cooled. *J Soc Indoor Environ Jpn*, 1998, 1: 41–50
- 95 Jo W K, Lee J H. Airborne fungal and bacterial levels associated with the use of automobile air conditioners or heaters, room air conditioners, and humidifiers. *Arch Environ Occup Health*, 2008, 63: 101–107
- 96 Schmidt M G, Attaway H H, Terzieva S, et al. Characterization and control of the microbial community affiliated with copper or aluminum heat exchangers of ACMV systems. *Curr Microbiol*, 2012, 65: 141–149
- 97 Acerbi E, Chénard C, Miller D, et al. Ecological succession of the microbial communities of an air conditioning cooling coil in the tropics. *Indoor Air*, 2016, 27: 345–353
- 98 Gu Q, Li X, Qu P, et al. Characterization of francisella species isolated from the cooling water of an air conditioning system. *Braz J Microbiol*, 2015, 46: 921–927
- 99 McJilton C E, Reynolds S J, Streifel S K, et al. Bacteria and indoor odor problems—Three case studies. *Am. Curr Microbiol*, 1990, 51: 545–549
- 100 Liu Y, Zhang W, Sileika T, et al. Disinfection of bacterial biofilms in pilot-scale cooling tower systems. *Biofouling*, 2011, 27: 393–402
- 101 Lucas M, Martínez P J, Viedma A. Comparative experimental drift study between a dry and adiabatic fluid cooler and a cooling tower. *Int J Refri*, 2008, 31: 1169–1175
- 102 Dondero T J J, Al E. An outbreak of legionnaires' disease associated with a contaminated air-conditioning cooling tower. *New Engl J Med*, 1980, 302: 365–370
- 103 Miyamoto H, Yamamoto H, Arima K, et al. Development of a new seminested PCR method for detection of legionella species and its application to surveillance of legionellae in hospital cooling tower water. *Appl Environ Microbiol*, 1997, 63: 2489–2494
- 104 Zheng C J, Wang X D, Wang P, et al. Investigation and analysis on hygienic status of centralized air conditioning in 699 large public

- places in Shanghai (in Chinese). *Occup Health*, 2009, 25: 1514–1516 [郑朝军, 王晓东, 王频, 等. 上海市 699 家大型公共场所集中空调卫生状况调查分析. *职业与健康*, 2009, 25: 1514–1516]
- 105 Liu Z, Liu Z Q, Zhao H Y. Humidifying effect affected by installation position of humidifier spray rod and nozzles direction (in Chinese). *Fluid Mach*, 2017, 8: 59–63 [刘哲, 刘泽勤, 赵航宇. 组合式空调机组加湿器喷杆安装位置和喷嘴朝向对加湿效果的影响研究. *流体机械*, 2017, 8: 59–63]
- 106 Xu Z W, Li Q, Wang Z C, et al. Air conditioning humidifier type statistics and comparison in China (in Chinese). *Constr Sci Technol*, 2015, 15: 140–141 [徐昭伟, 李强, 王智超, 等. 我国空调设备用加湿器型式统计及比较. *建设科技*, 2015, 15: 140–141]
- 107 Menzies D, Fanning A, Yuan L, et al. Hospital ventilation and risk for tuberculous infection in Canadian health care workers. *Ann Intern Med*, 2000, 133: 779–779
- 108 Hoge C W, Reichler M R, Dominguez E A, et al. An epidemic of pneumococcal disease in an overcrowded, inadequately ventilated jail. *N Engl J Med*, 1994, 331: 643–648
- 109 Myatt T A, Johnston S L, Zuo Z, et al. Detection of airborne rhinovirus and its relation to outdoor air supply in office environments. *Am J Respir Crit Care Med*, 2004, 169: 1187–1190
- 110 Wang Y L, Fu H L, Li Y P, et al. Influence of airflow pattern on indoor microbial aerosol (in Chinese). *Chin J Environ Eng*, 2016, 6: 3084–3090 [王廷路, 付红蕾, 李彦鹏, 等. 气流组织形式对室内微生物气溶胶的影响. *环境工程学报*, 2016, 6: 3084–3090]
- 111 Yuan D S, Tian H L, Gao J C. Numerical simulation to the effect of airflow distribution on air environment of air-conditioning room (in Chinese). *Constr Conserves Energy*, 2008, 9: 9–13 [袁东升, 田慧玲, 高建成. 气流组织对空调房间空气环境影响的数值模拟. *建筑节能*, 2008, 9: 9–13]

Summary for “空调通风系统对室内微生物气溶胶的影响研究”

Influence of air conditioning and mechanical ventilation (ACMV) systems on indoor microbial aerosols

Yan Wu^{1*}, Jiahui Rong¹ & Irvan Luhung²

¹ School of Environmental Science and Engineering, Shandong University, Jinan 250100, China;

² SinBerBEST Program, Berkeley Education Alliance for Research in Singapore (BEARS), Singapore

* Corresponding author, E-mail: wuyan@sdu.edu.cn

It is by now well established that most humans spend 70%–90% of their time in the mechanically ventilated buildings, in which the air conditioning and ventilation (ACMV) systems are commonly employed to provide fresh and clean air for indoor occupants. The air supplied to indoor environments inevitably passes over ACMV system and the interaction between the air and the ACMV surfaces can modify microbial air quality. Therefore, understanding how the ACMV influence biological aerosols can contribute to more incisive research to characterize indoor microbiology and associated health consequences. Such understanding is also essential for designing effective engineering controls to reduce bioaerosol exposure risks.

In this systematic review, the content is organized into two main sections. In Part one—Influence of ACMV major components on indoor bioaerosol, commonly means the components could directly reduce or increase the indoor microbial bioaerosol concentrations. Except outdoor bioaerosols, the major components on the ACMV system could be also potential microbe's resources. In this part, we summarize how do the major components, such as filters, heat exchanger, cooling tower and ventilation ducts, influence indoor bioaerosols. In the meantime, we emphasized an inspirational consideration that the ACMV system as a direct pathway could also spread the existing indoor microbes into other more indoor environment.

Part two (Influence to indoor bioaerosol by operation mode of ACMV) summarizes available information on many important processes of ACMV that could affect the concentrations and fates of indoor bioaerosol. This section begins by reviewing the state of knowledge regarding the factors related to the components themselves (design, material); following with the factors related to the physical and chemical environment around the components (temperature, relative humidity, and airflow). Then, the article proceeds to discuss several additional processes that can affect indoor bioaerosol levels: controlling the relative humidity of the ACMV system, selection of the appropriate ventilation rate, periodically cleaning the components such as filters and ventilation ducts, and removing moisture from the drain pan and heat exchanger accordingly.

In the conclusion, important challenges facing further studies are described along with several opportunities for near-term progress advancing knowledge about indoor microbial aerosols along with the interaction of ACMV system. Such progress is fundamental to efforts to better understand how the micro biome of indoor environments interacts with human health and wellbeing.

filter, ventilation ducts, heat exchanger, cooling tower, microbial aerosols

doi: 10.1360/N972017-01114