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# Natural Ventilation News

THE NEWSLETTER OF THE CIBSE NATURAL VENTILATION GROUP

www.cibse.org/nvg

## About Natural Ventilation News

This Newsletter is produced by the CIBSE Natural Ventilation Group Management Committee to inform members and potential members of the work being undertaken by the Group to benefit the discipline of natural ventilation within CIBSE. The management committee wish to encourage contact with all interested partners. Communication can be directed to the Group at the CIBSE Offices or to individual Management Committee members.

## Disclaimer:

The views and opinions in this journal are those of the authors and do not necessarily reflect those of their employers or the CIBSE Natural Ventilation Group.

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# A message from the chair

Chris Iddon

It's just over a year since our last newsletter which was issued during the first UK lockdown. Back then I postulated that seismic changes were afoot with how, as a society, we may embrace some of the "new normal". Three lockdowns later, and already we see widespread debate about the necessity to travel daily to a workspace – with many workers continually asked to work from home where applicable. Should such work systems become widely adopted then, as ventilation enthusiasts, we need to continue to pursue excellence in domestic design: Greater thought given to preventing overheating and improving indoor air quality, ensuring a good holistic environment for both WFH and residential life.

Early in the pandemic, building service engineering bodies (including ASHRAE, REHVA and CIBSE) highlighted the concern for the role of aerosol transmission of the SARS-CoV-2 virus, with calls to ensure ventilation provision in indoor spaces was considered as part of the suite of mitigation measures. Over the course of the last year many engineers and scientists (including members of the CIBSE Natural Ventilation group) have been vocal in raising awareness of the role that poorly ventilated spaces play in increasing the transmission risk of SARS-CoV-2. For many, many years, the CIBSE Nat Vent group (along with other CIBSE SIGs) have been promoting the benefits of good, year round, ventilation designs to deliver healthy indoor spaces for occupants without compromising occupant comfort. This message, outside of such specialist interest groups, was rarely heard and has this last year been taking a more prominent role – culminating in a recent change to the Government slogan: Hands, Face, Space and Fresh Air.

From explanations on national TV news items, through to exhaustive webinar contributions from ventilation experts, this year has seen an increase


in public awareness to the need for good indoor air quality – especially during a deadly pandemic. Although there is much work still to do to ensure that the air is indeed "fresh" and further considerations to provide sufficient outside air to reduce transmission without compromising thermal comfort and energy use.

Opening a window is not a binary action, and more education is needed to better explain how smaller openings can deliver the same air flow in colder weather as a larger opening in warmer weather. There is an art to designing good natural ventilation openings to deliver good control of airflow, providing high airflows for ventilative cooling in summer months and enabling good mixing of cool air to provide temperate air to occupied zone in winter months are just a couple of examples of the considerations needed for good natural ventilation design. Indeed, natural ventilation solutions may also need to work in concert with other ventilation systems with heat recovery for more optimal and energy efficient operation in the heating season.

Last year many CIBSE volunteers worked hard and rapidly to produce the CIBSE Emerging from Lockdown suite of guidance, which was made readily available to all https://www.cibse.org/coronavirus-covid-19/ emerging-from-lockdown. The authors of this guidance have received special commendation from the CIBSE President for their endeavours. This suite included the CIBSE Covid-19 Ventilation Guidance, which now on its fourth version, included contributions from members of the CIBSE Nat Vent group. Since May 2020, many Government guidance documents have cross referenced this document as the go to source for indoor ventilation advice – demonstrating how the work of CIBSE volunteers can have real impact in improving indoor ventilation, and I am sure that this document will have helped in reducing secondary transmission of SARS-CoV-2 during the ongoing pandemic.

In last year's newsletter I said "Now, more than ever before, it is prudent on building service engineers to take the lead and work towards a future of improved indoor environments." A statement that remains very much contemporary and in this edition of the newsletter two research teams describe their recently UKRI funded programmes to focus on this issue. Co-TRACE will be focussing on ventilation provision in the education sector and how it can be used to mitigate transmission of airborne pathogens, whilst the AIRBODS team will be undertaking similar studies in other non-domestic spaces. Using combinations of field studies and validated modelling these teams will aim to build on the rich evidence base on the role that ventilation has on creating healthy indoor spaces and reducing the transmission risk of SARS-CoV-2 and other pathogens.

Overheating indoor spaces continue to be a significant burden on occupant comfort and health. Using mechanical means for cooling can be energy intensive so utilising night-time ventilative cooling is an often used design strategy – bringing in cooler night air to pre-cool an indoor space prior to occupation. In this newsletter, Nick Wise looks at how unbalanced airflow can affect the time to purge a space. With a high and low level opening, cold air will start coming in through the high level opening at some point, leading to unbalanced flow and this will change the calculated purging time.

## NVG Podcast

Earlier this year the CIBSE Natural Ventilation Group organised a podcast with the CIBSE Journal discussing how Covid-19 has affected the way that buildings are ventilated. The episode can be listened to via the following link:

https://www.cibsejournal.com/uncategorized/podcast-how-covid-19-has-affected-the-way-buildings-are-ventilated/

# CO-TRACE – Supporting Healthy Schools

*Sophy Bristow, Cambridge University*

UK schools re-opened in March and with the recent increased awareness of airborne transmission of COVID-19, there is an ongoing need to quantify the risk, evaluate the effectiveness of mitigation measures, monitor the situation and provide guidance on ventilation best practice. This will become even more pressing as we head into next Autumn and Winter when colder weather will lead to potential conflict between managing airborne infection risk (high outdoor air ventilation rates), energy consumption and occupant comfort.

Lead by Prof Paul Linden (University of Cambridge), Dr Henry Burridge (Imperial College London) and Prof Prashant Kumar (University of Surrey), the aim of the COvid-19 Transmission Risk Assessment Case studies - Education establishments (CO-TRACE ) project, is to develop techniques to assess the absolute risk of infection in a given indoor space, using field studies in primary and secondary schools, complemented by laboratory experiments and CFD to elucidate the flow patterns responsible for airborne transport. The understanding generated will underpin recent developments in infection modelling to predict the likelihood of airborne transmission within schools. Our hope is that the project will reduce the uncertainties associated with airborne transmission routes and provide evidence to evaluate mitigation measures.

For the initial phase of the project, we will be working with at least nine schools across London, Surrey and Buckinghamshire to monitor levels of $CO_2$ in classrooms and other sites inside school buildings. We will investigate how changes to ventilation, classroom lay-out and occupancy profiles impact measured levels of $CO_2$. Schools will be monitored in the summer term and, where possible, in the autumn term too, so comparisons can be made. We will combine our field measurements with a program of school engagement, asking teachers and students what they would like to discover, co-designing the experiments, and engaging school communities in a discussion around possible solutions.

Indoor flow is strongly affected by the locations of windows or vents, heat rising from occupants/equipment and disturbances caused by people movement. During phase-2 of CO-TRACE we will therefore develop representations of these processes in the laboratory and CFD to interpret the monitoring data from our partner schools, which are typically single point measurements.

The CO-TRACE methodology will ultimately be applicable to all manner of indoor spaces, including shops, restaurants, offices etc. In this way, we hope it can support healthy school communities and also help to inform wider decisions about how we return to and use our buildings both during and after the pandemic.

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# Introducing AIRBODS – champions for ventilation in the battle against Covid-19

*Darren Woolf (Wirth Research)*

Airborne Infection Reduction through Building Operation and Design for SARS-CoV-2 (AIRBODS) is a UKRI-funded research programme led by Prof Malcolm Cook at Loughborough University in partnership with University College London, the University of Nottingham, the University of Cambridge, the University of Sheffield, London South Bank University and Wirth Research.

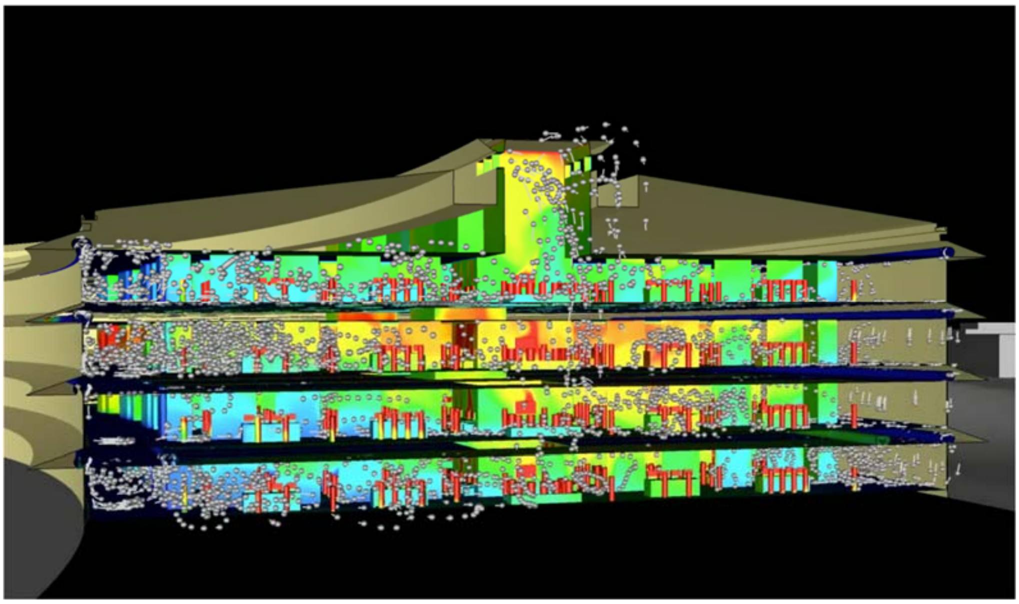

*Image courtesy of Wirth Research'*

The need to better understand airborne transmission of viruses such as SARS-CoV-2 within the built environment is now undeniable. It is well recognized that indoor locations, particularly when poorly ventilated, can increase the risk of infection transmission. Over the 18-month programme, leading UK scientists and engineers including many of the authors of the CIBSE COVID-19 ventilation guidance will be using experimentation, simulation, analysis and fieldwork to explore the physical and biological fate and transport of aerosols carrying virus particles under various scenarios. The AIRBODS team will develop guidance on how to design and operate buildings to minimize the risk of airborne transmission acknowledging any implications on energy use and thermal comfort (especially in winter) along with indoor air quality and occupancy levels as a combined consideration. With CIBSE as a project partner their work will also provide guidance on the application of current simulation and analysis tools to more accurately estimate the benefits of possible mitigation measures that could be used to reduce airborne transmission.

Key questions being considered include: what do we mean by 'poor' and 'sufficient' ventilation? How does ventilation and air movement affect transmission? What's an acceptable balance between conflicting drivers such as air change rate and energy consumption? To what extent can we use indoor air properties such as $CO_2$, air temperature and relative humidity as proxies for airborne transmission risk?

The impact of the Covid pandemic on the lives and livelihoods of everyone around the world has been substantial. There will be many repercussions in the coming years as part of the endeavour to design and operate safer environments within which we live and work. Some guidance has already been given on the opening up of shared indoor spaces, essential for economic recovery and mental wellbeing, as part of an emerging evidence base. The development of validated biophysics models within this project with a built environment context, together with better wellbeing standards supporting better indoor air quality and productivity, can only be further supported by an increased industry and public focus on ventilation and understanding of airborne transmission risk.

As a result, the impact of this work will be highly dependent upon how its messages are communicated beyond the built environment community to the medical community, the wider public and policy makers. Supporting the global research initiative borne out of this pandemic and UK funded research such as the new CO-TRACE programme focusing on the education sector, the AIRBODS team are poised to make a lasting impact on the understanding and mitigation of indoor virus transmission risk.
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# Unbalanced Exchange Flow and its Implications for Night Cooling

*Nick Wise and Gary Hunt, University of Cambridge*

## Background

An important part of the summertime ventilation strategy of many naturally ventilated buildings is night cooling. This is the practice of utilising ventilation openings during the night, when the external air temperature is at its coolest, in order to purge the building of excess heat that has accumulated during the day. This purge also has the effect of cooling the thermal mass of the building, reducing radiative temperatures during the following day.

The ability to predict the flow rates during a night purge and therefore the time taken for the purge to be complete is important in the design of natural ventilation systems. However, a recent paper[1] by the authors shows that our current model of night cooling is not complete and that a transition between flow patterns will occur. This finding has important implications for the design of some natural ventilation systems.

## Purging by displacement flow

The intended flow pattern for the night cooling of a single room is typically a displacement flow (Figure 1), whereby the flow is driven by hydrostatic pressure differences. For a room of height $H$, with a high-level opening of area $a_1$ and a low-level opening of area $a_2$, there is a well-established theoretical model for predicting the ventilation flow rate associated with displacement flow[2],

$$Q_{disp} = A^* \left(\frac{gh(T_r - T_\infty)}{T_\infty}\right)^{1/2}$$

where $h$ is the instantaneous depth of the warm air layer to be purged, $g$ is the acceleration due to gravity, $A^*$ is the effective area[3]

$$A^* = \left(\frac{1}{2c_1^2 a_1^2} + \frac{1}{2c_2^2 a_2^2}\right)^{-1/2}$$

and $c_1$ and $c_2$ are loss coefficients associated with the openings. The room is initially full of warm air at temperature $T_r$ and surrounded by cooler outside air of temperature $T_\infty$, with no heat sources in the room. The warm air is purged from the room by

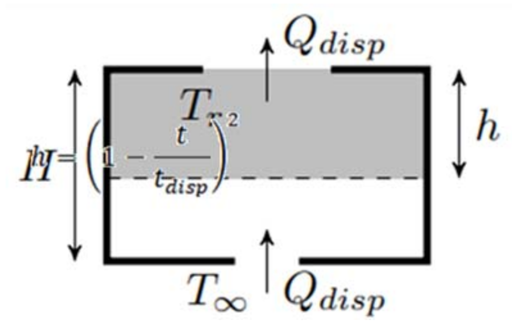


*Figure 1. Displacement flow.*

the displacement flow, the instantaneous depth of the layer of warm air being given by[4] ,

$$h = \left(1 - \frac{t}{t_{disp}}\right)^2,$$

where the emptying time $t_{disp}$ is

$$t_{disp} = \left(\frac{2S}{A^*}\right)\left(\frac{HT_\infty}{g(T_r - T_\infty)}\right)^{1/2}$$

As such, the model is based on the assumption that the temperatures of the external environment and the warm layer remaining constant during the purge – a reasonable simplification to make given the relatively short purge times and high levels of insulation in modern buildings. Substituting the equation for the layer depth into that for the displacement flow rate we find that

$$Q_{disp} = A^* \left(\frac{g(T_r - T_\infty)}{T_\infty}\right)^{1/2} \left(1 - \frac{t}{t_{disp}}\right)$$

This clearly shows that during a night purge, the flow rate decreases linearly with time, until at $t = t_{disp}$ the flow rate has reduced to zero and the purge is complete.

## Unbalanced exchange flow

However, another flow pattern is possible, known as unbalanced exchange flow (Figure 2). Whereas, with a displacement flow, there is unidirectional flow in through the low-level opening and out through the high-level opening, with an unbalanced exchange flow there is simultaneously flow into and out of the high-level opening.

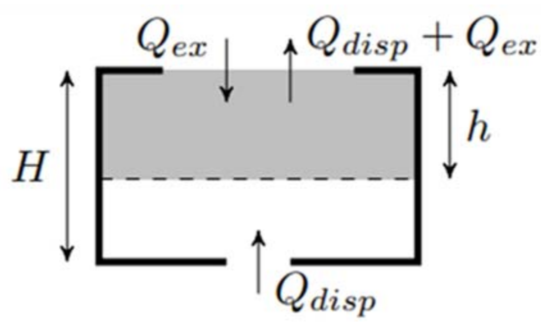

Figure 2. Unbalanced exchange flow.

Unbalanced exchange flow has been observed experimentally, both in the context of rooms[5] and ocean outfalls[6], but has only recently been modelled theoretically[7]. The flow was modelled by considering the superposition of displacement flow and balanced exchange flow[8], in other words, by recognising that the overall flow comprises both displacement and exchange flow components.

Wise & Hunt (2020)[7] showed that unbalanced exchange flow through a horizontal circular opening occurs when

$$Q_{disp} < 0.3c_1^{5/4}a_1^{5/4}\left(\frac{g(T_r - T_\infty)}{T_\infty}\right)^{1/2}$$

This inequality has an important consequence. Displacement flow theory predicts that, whatever the flow rate at the start of a night purge, by the end of the night purge the flow rate has reduced to zero. However, if there is displacement flow at the start of the purge then this inequality indicates that there will be a time when the flow rate has reduced below the value at which unbalanced exchange flow initiates. This means that all displacement flows will transition to unbalanced exchange flow, regardless of the relative size of the opening areas[1].

## Implications

After the displacement flow has transitioned to unbalanced exchange flow, the displacement flow model that was used to derive the emptying time, $t_{disp}$, is no longer valid. So how long will it take the night cool to finish?

An important difference between unbalanced exchange flow and displacement flow is that we now have cool air coming through the high-level opening and entering the layer of warm air. There will inevitably be some mixing between the warm air and the incoming cool air, so the temperature of the warm layer will decrease - by contrast, we recall the warm layer temperature remains constant during the earlier displacement flow stage. That decrease will in turn reduce the temperature difference driving the flow.

Whilst the amount of mixing caused by the cool air descending through the high-level opening is not known currently, we have shown[1] that as long as there is some mixing, the warm layer will never be completely purged from the room. Instead, the layer will become thinner and thinner, whilst its temperature reduces towards that of the outside but never reaching the outside temperature.

How much does this matter? Should we revisit the calculations for every natural ventilation design that relies on night cooling? Fortunately, the answer is no. Substituting the equation for displacement flow into the inequality, we can rearrange and find that we get unbalanced exchange when

$$h < 0.09\frac{a_1^{5/2}}{A^{*2}}$$

For a typical single-story room with high and low-level openings of equal area, we only get unbalanced exchange flow when the layer depth is around 1% of the room height. With such a shallow layer, the assumption that the pressure distribution in the layer is hydrostatic is no longer valid and so the model breaks down. In any case, for practical purposes we may consider a night purge to be essentially complete if we have removed 99% of the warm air from the room.

For taller rooms however, or rooms where the area of the high-level opening(s) is substantially greater than that of the low-level opening, the effect of unbalanced exchange flow cannot be ignored. If the area of the high-level opening is 10 times greater than that of the low-level opening, unbalanced exchange flow can initiate when less than 20% of the warm air has been removed from a single-storey room. Although all the warm air will never be removed from the room, we can calculate the time for 99% of the warm air to be removed. In this case, the time to remove 99% of the warm layer is over 2.5 times longer than the emptying time, $t_{disp}$, we would calculate if we neglected unbalanced exchange flow. In this case then, unbalanced exchange flow plays a dominant role during a night purge.

In Wise & Hunt[1] we also compare unbalanced exchange flow with balanced, i.e. when there are no low-level openings (perhaps because they are shut for security reasons). We find that a room with no low-level opening purges 99% of the buoyancy around 30(!) times slower than one with a low-level opening a tenth of the area of the high-level opening.

## Conclusions

Any room undergoing night cooling via displacement flow will likely transition to unbalanced exchange flow, with the effect that theoretically no room will ever be completely purged of warm air. However, for many typical rooms this effect can be neglected as by the time the transition occurs, almost all the warm air will have been removed.

For other geometries however, namely those that are very tall or have a much greater area of openings at high-level compared to low-level, the effect of unbalanced exchange flow can be significant. The time to remove nearly all the warm air from such a room more than doubles when compared to the emptying time predicted for displacement flow alone. However, this is still far better than with no low-level opening at all, for which purging times are an order of magnitude longer. Natural ventilation designers should keep the existence of unbalanced exchange flow in mind when calculating the emptying time for a night cool strategy. A secure, automated low-level opening should be included for night cooling if at all possible, even if it is much smaller than the high-level openings.

## References


1. Wise, N. and Hunt, G.R. 'Unbalanced Exchange Flow and Its Implications for the Night Cooling of Buildings by Displacement Ventilation'. Environmental Fluid Mechanics, 19 March 2021. https://doi.org/10.1007/s10652-021-09785-7.

2. Thomas, P.H. 'Investigations Into the Flow of Hot Gases in Roof Venting'. Fire Research Technical Paper No. 7, 1963.

3. Aynsley, R.M., Melbourne, W.H., and Vickery, B.J. Architectural Aerodynamics. Architectural Science Series. Applied Science Publishers, 1977.

4. Linden, P.F., Lane-Serff, G.F., and Smeed, D.A. 'Emptying Filling Boxes: The Fluid Mechanics of Natural Ventilation'. Journal of Fluid Mechanics 212 (March 1990): 309–35. https://doi.org/10.1017/S0022112090001987.

5. Hunt, G.R., and Coffey, C.J. 'Emptying Boxes - Classifying Transient Natural Ventilation Flows'. Journal of Fluid Mechanics 646 (March 2010): 137–68. https://doi.org/10.1017/S0022112009993028.
6. Wilkinson, D.L. 'Avoidance of Seawater Intrusion into Ports of Ocean Outfalls'. Journal of Hydraulic Engineering 114, no. 2 (1988): 218–28. https://doi.org/10.1061/(ASCE)0733-9429(1988)114:2(218).
7. Wise, N.H., and Hunt, G.R. 'Buoyancy-Driven Unbalanced Exchange Flow Through a Horizontal Opening'. Journal of Fluid Mechanics 888 (April 2020). https://doi.org/10.1017/jfm.2020.55.
8. Epstein, M. 'Buoyancy-Driven Exchange Flow Through Small Openings in Horizontal Partitions'. Journal of Heat Transfer 110, no. 4a (1988): 885–93. https://doi.org/10.1115/1.3250589.