CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 10

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Heiselberg, P. K. (Ed.) (2016). *CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 10*. Department of Civil Engineering, Aalborg University.

An Methodology for Quality Control and Draught Assessment of Room Ventilation Supply Using Laser Light Sheets

Christian A. Hviid[#12], Steffen Petersen[*3]

[#]*Department of Civil Engineering, Technical University of Denmark*
Brovej building 118, DK-2800 Kgs. Lyngby, Denmark

[1]cah@byg.dtu.dk

[#]*Saint-Gobain Nordic*

Robert Jacobsens Vej 62A, DK-2300 Copenhagen S, Denmark

[2]christian.hviid@saint-gobain.com

[*]*Department of Engineering, Aarhus University*
Inge Lehmanns Vej 10, DK-8000 Aarhus C, Denmark

[3]stp@eng.au.dk

Abstract

A common technique to investigate draught problems in a room is to make spot measurements of air velocity. This might identify where the draught problem is located but it does not necessarily identify the distribution and source of the problem. Usually visual inspections of the location of ventilation inlet and smoke experiments are next step to track the draught source. However, these methods do not provide an understanding of the air flow pattern in the room with sufficient resolution to necessarily identify the source of the draught problem. However, laser light sheets together with smoke seeding for on-site visualization of airflow in rooms might be useful for tracking down draught sources in rooms as part of a commissioning process. This paper reports on the first attempts to use this simple method to visualize and characterize air flow patterns in two different classrooms. The visualizations disclosed the air movements, and it was possible to record the movements using a standard smartphone camera. From the movements it was possible to qualitatively assess the overall airflow patterns of the room. The resolution of the video recording was also sufficient to be processed in particle image velocimetry software to gain overall flow pattern visualization, if not accurate readings. The latter result indicates that there could be a potential for real-time velocimetry processing by smartphones but the method in general needs further investigation and documentation.

Keywords - visualization, laser light sheet, ventilation, draught, PIV

1. Introduction

In the indoor environment, air currents are constantly flowing all around us. Some of these air currents are forced e.g. by the ventilation system in the room, some are buoyant flows e.g. due to thermal loads or cold surfaces in the room. The air currents are invisible to us; however their influence on our thermal well-being is substantial. Whole-body thermal comfort is known to be affected by relative air velocity [1] to affect local discomfort on parts of the body [2]. During the design phase of a ventilation system, a focus on ventilation effectiveness and avoiding elevated air velocities is therefore essential. However, discrepancy between design and practice are often experienced in the form of draught complaints from occupants. Many of these problems may have been avoided through a proper commissioning process, i.e. a control process that ensures that the operating conditions correspond to the design conditions.

But identifying the specific reason and source of the notion of draught is difficult. A common method is to use a point-by-point method where thermal anemometers are moved randomly around in the occupied zone in the hope of disclosing the source of draught. The alternative is whole-field measuring techniques like particle image velocimetry (PIV), particle streak velocimetry (PSV), and schlieren photography [3]. With these techniques, the air movements on a large scale can be recorded and processed by digital image software to quantify the fluid motions. Results have been reported for different full-scale applications, like car and aircraft cabins [4-5], and rooms [6-9]. However, such methods are rarely applied outside laboratories because the equipment is either expensive or it seems too time consuming to obtain results that really adds value. Sun & Zhang [10] did try to operationalize PIV to be applicable in multiple full-scale ventilated spaces using helium-filled soap bubbles as seeding and they even reported a price tag of USD 15000. Nonetheless, PIV has only seen rare application as a commissioning tool in the ventilation industry. This paper reports on the first steps towards a practical applicable quality control method for ventilation systems in classrooms, offices, patient wards and other rooms. The idea is to employ less expensive equipment and simpler ways to capture the air currents in two classrooms, identify sources of draught, and obtain sufficient commissioning information.

2. Methodology

The method is based on the use of laser light sheets to visualize air flow patterns. A laser light sheet is created with special lenses that divert the laser light into a narrow sheet, in effect creating a 2D slice of the room only some millimeters wide. When the light hits smoke particles seeded into the air, the scattered light can be observed by the human eye and the air movements are visualized. Due to the 2D-nature of the sheet, only motions in the plane of the sheet are visible. One advantage of using laser in combination with smoke over smoke alone is the long-lasting observation period. Smoke scatters quickly and dissipates into a fine haze that is unable to illustrate any air currents. That same haze can be illuminated by the laser enabling the user to evaluate the air currents over much longer periods of time. The laser illuminates only the smoke particles in the plane, while leaving the particles in front of the plane and behind the plane invisible. The advantage of using smoke over helium-filled bubbles is the simplicity, availability of smoke generators, and the particle seeding generation rate.

2.1 Equipment

The employed laser was a Raypower CW 5W from Dantec Dynamics with a 90° mirror unit, a focus module and three diverging lenses attached to form the light sheet.

The laser power is several orders of magnitude smaller than has been postulated to be necessary for a room-scale application [10].

An ordinary smart-phone camera with the ordinary lens was used to record the action at 120 frames per second and a resolution of 1920x1080 pixels. To record the scale of the fluid motions a 10x10cm web of white string stretched out by a wooden frame was used, sometimes with a black backplate to increase the signal-to-noise ratio. The web provided a measuring utility for air speed assessment. Thus, it was possible to estimate the overall traveling speed of the air by noting the position of a particular eddy at time zero when it became visible by entering the light sheet and the position and time when it exited the sheet.

The velocities were compared to the measurements from omnidirectional thermal anemometers, which were placed in the light sheet at locations of interest. The thermal anemometers were from www.sensor-electronic.pl, model SensoAnemo 5100 LSF, calibrated ultimo 2015.

To test how much data could be derived from the recordings, some frames were processed in the freely available digital imaging software PIVlab [11-13].

3. Test cases

The method was tested in two classrooms that were built or refurbished recently, one with a diffuse ventilation ceiling, one with four swirl diffusers. No pupils were present during the experiments. The supplied air flow rate was estimated to be 800 m^3/h in case 1 and measured to be 900 m^3/h in case 2. In the classrooms, the laser was placed along one wall on a trolley or similar and moved forwards in incremental steps of 1.0 m to create visual 2D slices of the room, see Fig. 1. In both test cases this was deemed sufficient to disclose any high airspeed areas of interest. In one instance, thermal anemometers were placed at the critical positions to directly measure the magnitude of the flowing air.

Different tests were carried out to develop the methodology and learn advantages, disadvantages, obstacles and improvements to the method. The tests that are reported in this paper are summarized in Table 1.

Table 1. The reported tests are categorized in either tests of certain ventilation details, or whole-field investigations

	Details	Whole-field
Test case #1, diffuse	Exhaust flow, plume flow	Buoyant flows
Test case #2, swirl	--	Jetdrop

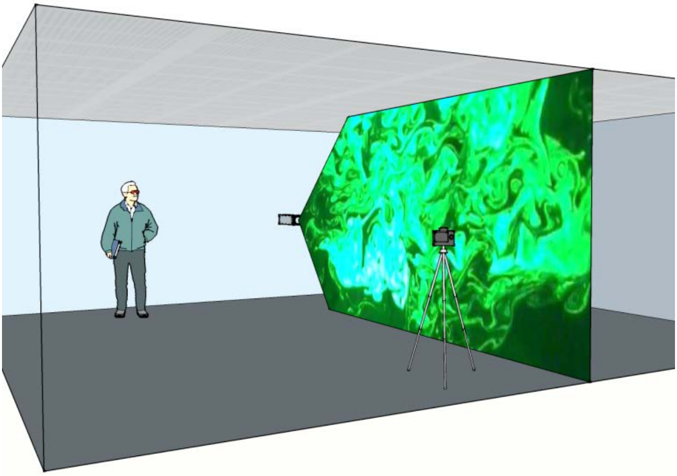


Fig. 1 Depiction of the test setup with laser and camera. The position of the camera is the most favourable viewing angle where the scattered light is most intense.

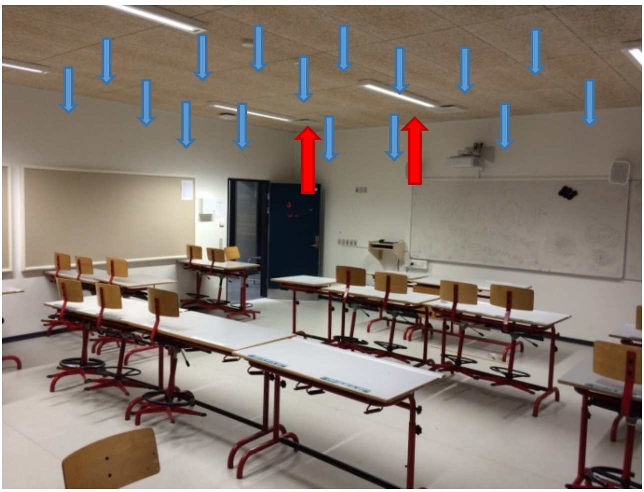


Fig. 2 Photo of classroom #1 with a diffuse ventilation ceiling. Three exhaust grilles are placed in the ceiling in a line parallel to and above the white board. Only two of exhaust are visible on the photo.

Fig. 3 Photo of classroom #2 with four swirl diffusers in the ceiling.

4. Results

To test how the laser light sheet improved the information level, a test was run in classroom #1 with only smoke and one with smoke and laser. Fig. 4 shows a screen dump of the smoke test resulting in a video showing smoke circulating, downwards in the foreground and upwards in the background. Fig. 5, now with the laser sheet on, only illuminates the particles in the light sheet, which creates a much clearer picture of air streams out through the exhaust vent.

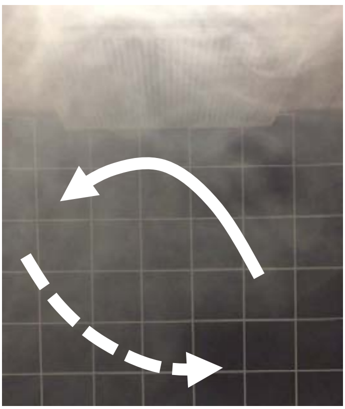


Fig. 4 Seeded smoke occludes fore- and background (frame 1263). Air currents are circular, no clear exhaust stream.

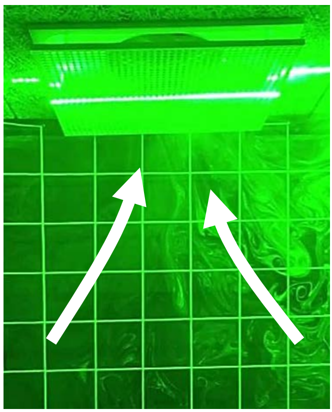
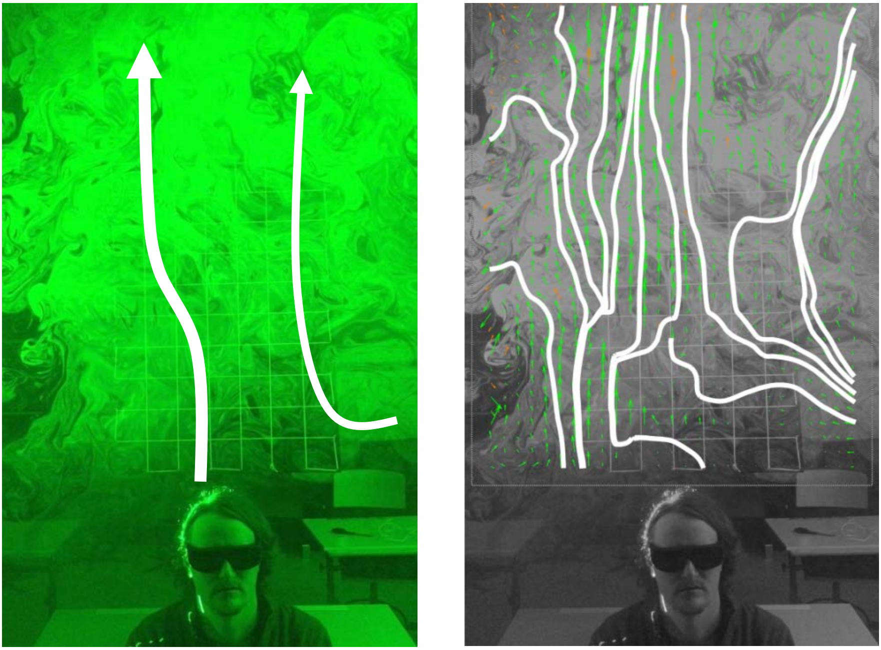


Fig. 5 Seeding in light sheet is visible (picture shown at frame 2277). Exhaust stream is very clear.



(a) (b)

Fig. 6 Thermal plume rises on left side of the picture (a) and reaches ceiling at a speed of approx. 0.3 m/s. Plume on right side is blocked and diverted by air entering from the right side. The video material has sufficient resolution to be interpreted by PIVlab to show the overall flow pattern (b).

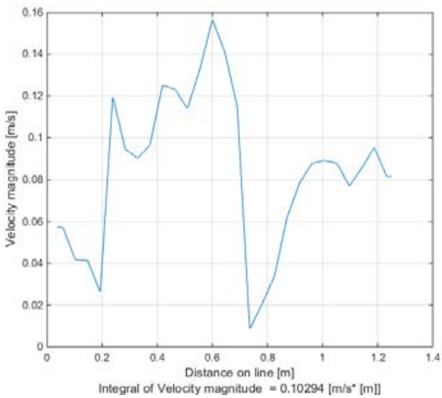
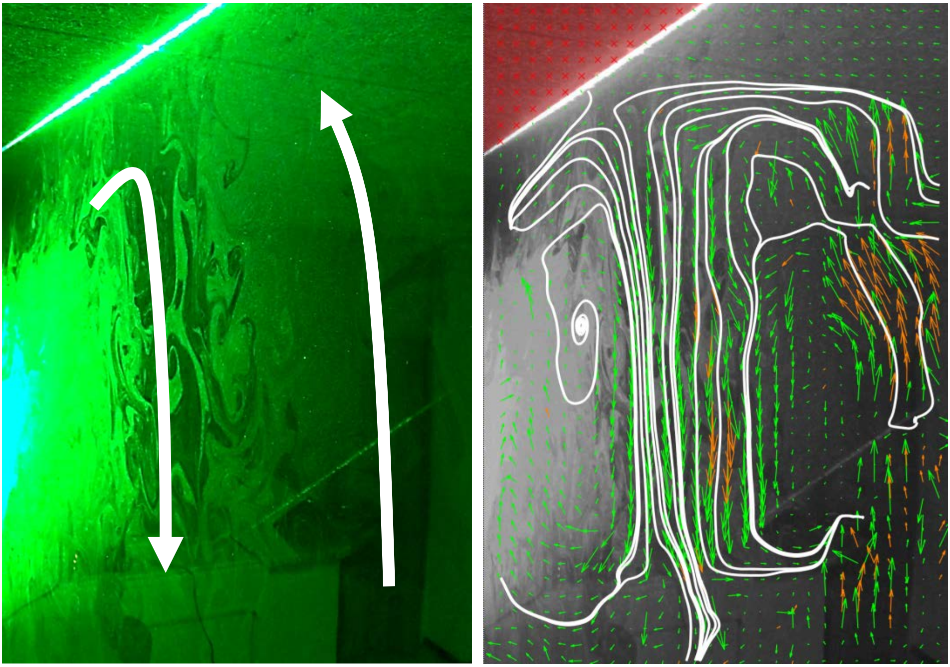


Fig. 7 The speed of the thermal plume approx. 1 m above the head of the occupant.. The maximum velocity is approx. 0.16 m/s. Data from PIVlab.

Fig. 6a shows the thermal plume of an occupant with the overall flow patterns shows by arrows. Fig. 6b shows the same picture when it has been processed by PIVlab. The orange vectors are interpolated [14] yet it seems that some of the vectors are missing, perhaps because the resolution of the video recording material was not sufficient. Also the assessed speed of the plume is almost double that of the PIVlab derived speed of 0.16 m/s (Fig. 9). Consequently this is an issue for further scrutiny. However, the overall flow patterns are quite accurately derived by PIVlab.

Also Fig. 7a-b shows pictures processed by PIVlab. The overall flow patterns are recognizable with significant buoyant flows in congruence with the literature on diffuse ceiling ventilation [15].

In Fig. 8 (in classroom #2) colliding jets generates waves of cooler air that are being diverted towards the heads of the occupants.



(a) (b)

Fig. 8 Air currents seeemingly governed by buoyant forces rises in some areas and drops in other areas (a). This fits well with the expected behaviour of diffuse ventilation when forced flow is absent (frame 552). The video material has sufficient resolution to be interpreted by PIVlab (b) to show the overall flow pattern

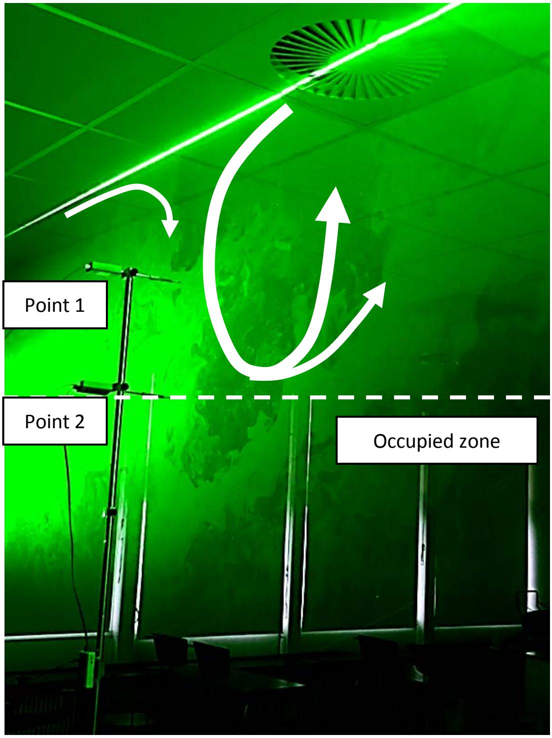


Fig. 9 Colliding jets from swirl diffusers diverts the air stream downwards to the upper boundary of the occupied zone at approx. 2,0 m (frame 744)

Thermal omnidirectional anemometers were placed in the jet drop to measure the magnitude of the air speed with the results shown in Table 2. These readings seem quite small, especially the standard deviation, when considering the turbulence at the measurement positions. The anemometers are recently calibrated; consequently this is an issue for further scrutiny.

Table 2. Air speed readings with standard deviation from thermal anemometers.

Air speed	Thermal anemometers
Point 1	0,22±0,03
Point 2	0,12±0,02

5. Discussion and improvements

Our first practical experience using laser sheets in actual classrooms indicates that a larger light sheet probably is necessary in classrooms. The mounted diverging lens of

30° required more than 5 m of room before the light sheet extended the full height of the room. Preferably, a lens of 90° would only need 1.5 m. The consequence of a more wide lens is that the light intensity will be is reduced and the signal-to-noise ratio will rise, but this is probably not a practical problem since the full power of the applied laser was never used during the tests. Another issue encountered in the test was that using a powerful laser resulted in diffuse reflections of the laser light sheet from room surfaces (i.e. lit up the entire room) making it more difficult to see the laser sheet itself. To overcome this and increase the signal-to-noise ratio, we suggest employing a movable slightly perforated screen of black material opposite the laser to absorb, and not reflect, the laser light. The same black screens could be used as background for the video recordings of the laser light sheet to enhance the signal-to-noise ratio. From a practical perspective, the procedure of the proposed methodology needs some refinements to reduce the time spent before any useful results are generated.

Further development of the laser sheet technique could be to enable the generation of multiple simultaneous light sheets to gain a 3D experience of air flow patterns. This could be done by splitting the laser beam into multiple light sheets, possibly in a hand-held manner, using flexible fiber-optics as suggested by Koga et al. [16].

The employment of PIVlab and the fact that simple software was able to derive the overall flow pattern from a relatively low-resolution, low-sensitive camera recording is very promising. Future work should encompass the development of specialized digital image processing apps for smartphones to create real-time quantification of the airflows.

6. Conclusion

Air currents in rooms are invisible to the human eye but can be visualized using a laser light sheet and smoke seeding. First practical experiences have indicated that this technique is more efficient to identify live fluid motion in classrooms than point-to-point measurements. The method still lacks development to be easily deployed in practice, and we have suggested a number of improvements to achieve this, e.g. larger room-size light sheet by more diverging lenses, splitting the laser beam into multiple light sheets, and a possibility for hand-held laser visualization using flexible fiber-optics. Overall, the first experience has demonstrated a value-creating potential for use of laser sheet visualization in building commissioning processes, especially if real-time velocimetry processing can be implemented together with the smartphone camera.

Further investigations of the above-mentioned issues and the development of elaborate practical guidelines for conducting laser light sheet investigations in the field is needed.

Acknowledgments

The authors wish to express their gratitude to the schools that has kindly allowed us to test the method in practice and also to Saint-Gobain Nordic for financing the utilized equipment.

References

[1] P. O. Fanger. Thermal Comfort: Analysis and Applications in Environmental Engineering, Copenhagen: Danish Technical Press, 1970
[2] J. Toftum. Air movement – good or bad? Indoor Air 14 (2004) 40–45
[3] M . Sandberg. Whole-field measuring methods in ventilated rooms. HVAC&R 13 (2007), 951-970. doi:10.1080/10789669.2007.10391464
[4] J.P. Lee, H.L. Kim, S.J. Lee. Large-scale PIV measurements of ventilation flow inside the passenger compartment of a real car. J. Vis. 14 (2001), 321–329. doi:10.1007/s12650-011-0095-9
[5] M. Kühn, J. Bosbach, C. Wagner, C. Experimental parametric study of forced and mixed convection in a passenger aircraft cabin mock-up. Build. Environ. 44 (2009), 961–970. doi:10.1016/j.buildenv.2008.06.020
[6] J. Li, X. Cao, J. Liu, C. Wang, Y. Zhang. Global airflow field distribution in a cabin mock-up measured via large-scale 2D-PIV. Build. Environ. 93 (2015), 234–244. doi:10.1016/j.buildenv.2015.06.030
[7] L. Zhao, Y. Zhang, X. Wang, G.L. Riskowski, L.L. Christianson, Q. Chen. Measurement of two-dimensional air velocities in a full-scale room using particle image velocimetry. ASHRAE Trans. 107 (2001), part 2, 434–444.
[8] A. Sattari. Investigations of Flow Patterns in Ventilated Rooms Using Particle Image Velocimetry. Ph.D. thesis, Royal Institute of Technology, Stockholm, Sweden, 2015
[9] P.Å. Elvsén, M. Sandberg. Buoyant jet in a ventilated room: Velocity field, temperature field and airflow patterns analysed with three different whole-field methods. Build. Environ. 44 (2009), 137–145 doi:10.1016/j.buildenv.2008.02.009
[10] Y. Sun, Y. Zhang. Development of a stereoscopic particle image velocimetry system for full-scale room airflow studies, Part II: Experimental setup. ASHRAE Trans. 109 PART 2 (2003), 540 – 548.
[11] W. Thielicke, E.J. Stamhuis. PIVlab – Towards User-friendly, Affordable and Accurate Digital Particle Image Velocimetry in MATLAB. Journal of Open Research Software 2(1):e30 (2014), doi:10.5334/jors.bl
[12] W. Thielicke, E.J. Stamhuis. PIVlab - Time-Resolved Digital Particle Image Velocimetry Tool for MATLAB (version: 1.41), 2014, doi: 10.6084/m9.figshare.1092508
[13] W. Thielicke. The Flapping Flight of Birds - Analysis and Application. Phd thesis, Rijksuniversiteit Groningen, 2014, http://irs.ub.rug.nl/ppn/382783069
[14] D. Garcia. A fast all-in-one method for automated post-processing of PIV data. Experiments in Fluids 50 (2011), 1247-1259
[15] P.V. Nielsen, E. Jakubowska. The performance of diffuse deiling inlet and other room air distribution systems the performance of diffuse ceiling inlet and other room air distribution systems. In: Proceedings of Cold Climate HVAC 2009, Sisimiut, Greenland, 16-19 March 2009
[16] D.J. Koga, S.D. Abrahamson and J.K. Eaton. Technical Note. Development of portable laser sheet, Experiments in Fluids 5 (1987), 215-216