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Discussions

Interactive comment on "Experimental evidence of condensation-driven airflow" *by* P. Bunyard et al.

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Concerning our submitted article, we are aware that the discussion is now closed. However, we would like to make a final comment, given that we have obtained experimental results which uphold the general conclusions of the original submitted manuscript.

Both Alex Kleidon and reviewer #1 made it clear that the circulation of air which we had obtained in the experiments described in the original MS, i.e. the clockwise flow down from the cooling tubes, went counter to that which had been described for the biotic pump theory, namely airflow upwards from the surface to the point of cloud condensation. They therefore questioned our conclusion that the prime cause of the downward flow was condensation and instead invoked air density changes brought about by the cooling of air close to the cooling tubes.

As a result of that valid comment, we recently carried out further experiments in which

we heated the air surface at the base of the right column by means of a heating mat. With the heating on, we then switched on the refrigeration. After 5 minutes we switched the refrigeration off for a further 5 minutes and then repeated the cycle for a number of times.

We had expected the upwards flow of air caused by the surface heating to show a significant reduction in flow during the periods of refrigeration, in line with the reviewers' comments that air density changes at the cooling coils were responsible for the observed airflow. That reduced airflow did not manifest itself: instead the air flow increased upwards during refrigeration as seen in the following graphs.

We have repeated the experiment a number of times, always with the heating mat switched on throughout the period of observation. The results are clear. The flow, both in intensity and degree, increases upwards during the cooling period, against the expectation that it would reduce.

As stated in the original MS, the kinetic energy associated with condensation is orders of magnitude greater than that associated with air density changes in exactly the same parcel of air, as it passes over the cooling coils. We had made mistakes (easily remedied) in the original calculations as presented in the submitted MS. Those errors have been dealt with and the recent experiments have been correctly evaluated.

Reviewer #1 had calculated that an air circulation involving the 20 cubic metres of air enclosed in the structure, at an average air density of 1.25 kg per cubic metre of air and an average air velocity of 0.2 m/s would require a minimum of 0.5 Ws of kinetic energy to drive it. He suggested that air density changes at the point of cooling would in all likelihood suffice, and that the kinetic energy involved in condensation would greatly exceed that required. Moreover, both reviewer #1 and Alex Kleidon indicated that condensation would lead to no net flow because of air imploding inwards from all around a point of condensation. They gave no support to their contention that condensation and the volume change cannot lead to uni-directional airflow.

Furthermore, even though the air density change at the cooling coils will result in air sinking down the right hand column, it is more likely to form an accumulating pool of cold, dense air at the base of the column than generate air circulation around the entire 20 metres volume of the structure. Be that as may, as pointed out below, we find that the kinetic energy associated with the cooling of air is insufficient by orders of magnitude to cause the air to circulate.

We do not agree with that description of the impact of condensation on airflow, maintaining that polar differences in atmospheric conditions will result in distortions in the airflow from condensation such as to give rise to uni-directional flow. In our experiments that flow can be either upwards- or downwards-directed, depending on the particular conditions during experimentation.

Having properly dealt with the errors in the calculations of the original MS, we are now in a position to evaluate correctly the kinetic energies involved in condensation and in air density changes. First and foremost, we find that the latent heat release from condensation is equivalent (though opposite in sign) to the kinetic energy associated with the partial pressure change when water vapour condenses to liquid water and ice on the cooling tubes. That finding indicates that in the atmosphere at large the latent heat release, rather than heating the air, will be 'consumed' in filling the partial void of volume loss. That obvious finding offers evidence that the volume change associated with condensation might well be responsible for the upward flow of air, with the energy of latent heat release providing the necessary force for air to move. The conservation of energy dictates that the energy required to generate the volume changes of water vaporization must be balanced by that required when vapour returns to its liquid and solid states.

The experiments of 15th December 2015 and of 2nd January 2106 were both carried out with floor mat heating. Both showed enhanced upward (anti-clockwise) flow of air during refrigeration: therefore, an increased intensity of flow against the counter-flow of air from air density changes.

In evaluating the kinetic energies associated with condensation and with air density changes of the same parcel of air, we used the observed data to give us a per second reading of the quantity of water vapour condensed and of the air density change. For both sets of data, as well as of the observed airflow, we then carried out a moving average encompassing one minute of data. In the graphs so obtained, we found that the airflow displayed a lag time in comparison with both condensation and air density. When we accounted for that lag-time by shifting the airflow data forward, we were able to see good correspondence (see graphs).

That correspondence offered us the opportunity to measure the kinetic energies associated with peak condensation and air density changes for a particular air flow (see graphs).

We can see from the attached table that the kinetic energy associated with the air density change falls far short (by more than two orders of magnitude) of that required to account for the observed air circulation, whereas the potential kinetic energy from condensation exceeds that required by a factor of between 2.5 and 4.

That excess of potential energy associated with condensation, when released in the form of latent heat, will account for factors such a friction, turbulence and the partial net flow in one direction from the point of condensation.

As a result of the recent experiments, with the example of 15th December 2015, we believe that we have shown beyond doubt that condensation is the most likely candidate for the observed directed airflow. We have to thank the reviewers for their important and valid critiques of the original manuscript. As a result of being able to experiment further, we have answered the critiques and produced evidence that our original premise was correct.

It is clear from the reviewers that the issue of condensation causing measurable airflow is critical and not to be ignored. We believe we have gone to considerable lengths to demonstrate the validity of our original premise. Without question, we need to revise certain sections of the original manuscript, accounting for the errors and adding in data and conclusions from the recent experiments. Much of the original would remain as is, with some paragraphs and graphs deleted to be replaced by others. In effect, the final manuscript is likely to be shorter and more explicit.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 12, 10921, 2015.

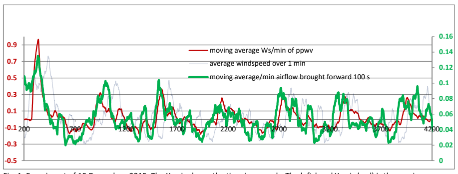

Fig. 1. Experiment of 15 December, 2015. The X-axis shows the time in seconds. The left-hand Y-axis (red) is the moving average (60 seconds of averaging) in Ws for the partial pressure change brought about through condensation at the cooling coils. The right-hand Y-axis is the moving average (60 seconds) of the upwards-directed airflow. The green curve is the airflow brought forward some 100 seconds such that the curve coincides with that of the condensation curve. The faint blue curve shows the average airflow without bringing the curve forward. In the experiment, the refrigeration is switched on and off 7 times in total. It is left on for 5 minutes and then off for a further 5 minutes.

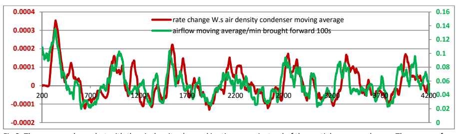

Fig.2. The same as above, but with the air density change kinetic energy instead of the partial pressure change. The curves of the partial pressure change and the air density change of the same parcel of air are similar, with the difference in the quantities involved. The left-hand Y-axis gives the units in Watt.seconds and we see a 2000-fold difference between the two.

KE condensation	KE air density change	Airflow	KE required to cause circular flow neglecting friction etc.	Ratio of required KE for circulation to KE potential from condensation	Ratio of KE potential from air density change to that required KE for circulation
0.26	0.00015	0.07	0.06	4.24	408.33
0.25	0.00017	0.08	0.08	3.13	470.59
0.26	0.00016	0.088	0.10	2.69	605.00
0.30	0.00017	0.094	0.11	2.72	649.71
0.32	0.00016	0.104	0.14	2.37	845.00
0.37	0.00022	0.11	0.15	2.45	687.50
0.96	0.00035	0.14	0.25	3.92	700.00

Fig. 1. Experiment 15 Dec, 2915 with table