Moisture Movement in Porous Masonry – New Findings

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BACKGROUND

- I am an Electronic Engineer, currently PhD student on Architectural Conservation, University of Strathclyde
- We have been operating since 2014.
- Our initial motivation was to research and better understand rising damp, one of the most controversial topics in building conservation, however the research became much wider in scope, encompassing many moisture-related phenomena: breathability, condensation, the effect of heating, evaporation etc.
- Our investigation led to several very important discoveries.

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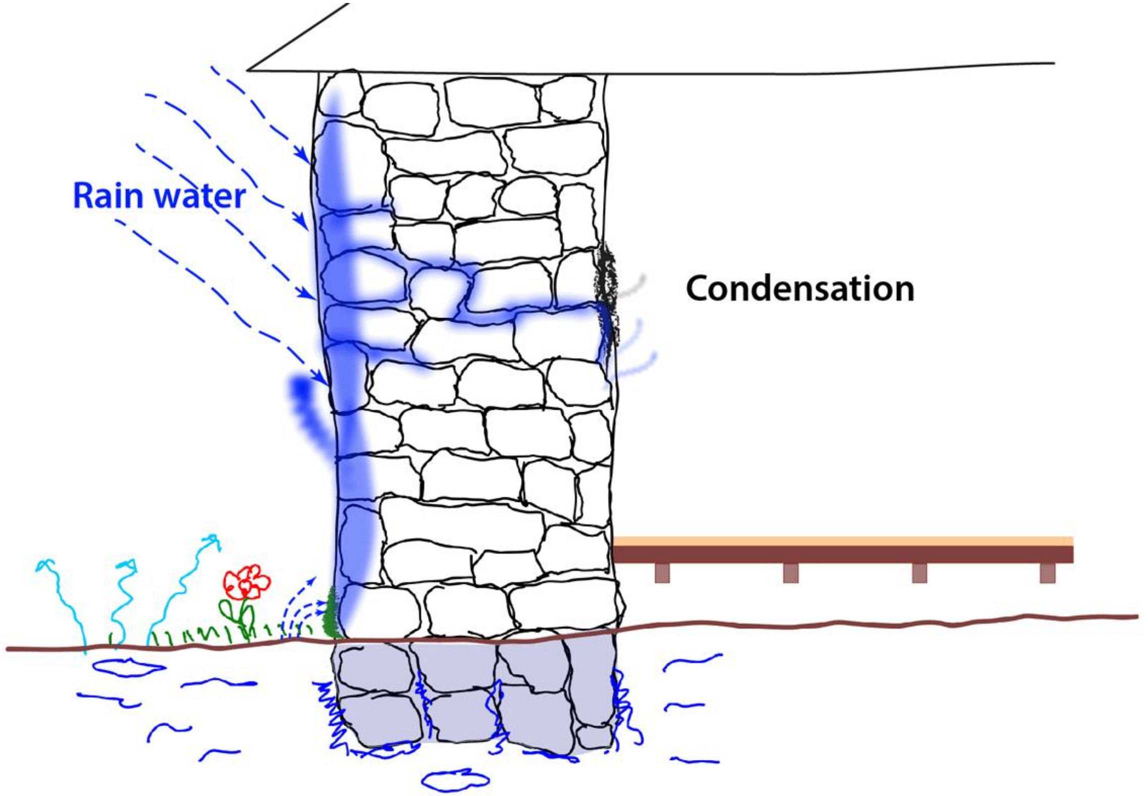
AGENDA

- Main Moisture Sources
- Soil Evaporation: the hidden moisture source
- Breathability: new findings

MOISTURE SOURCES

- It is commonly believed that old buildings are affected by **2 main moisture sources**:

1. **WATER ingress**: primarily rainwater + broken pipes. Several forms:
    - Roof leaks
    - Chimney leaks
    - Gutter leaks
    - Driving rain
    - Water splash back at the base
    - Etc.
2. **CONDENSATION**:
    - Caused by thermal bridging (hot-cold interaction)



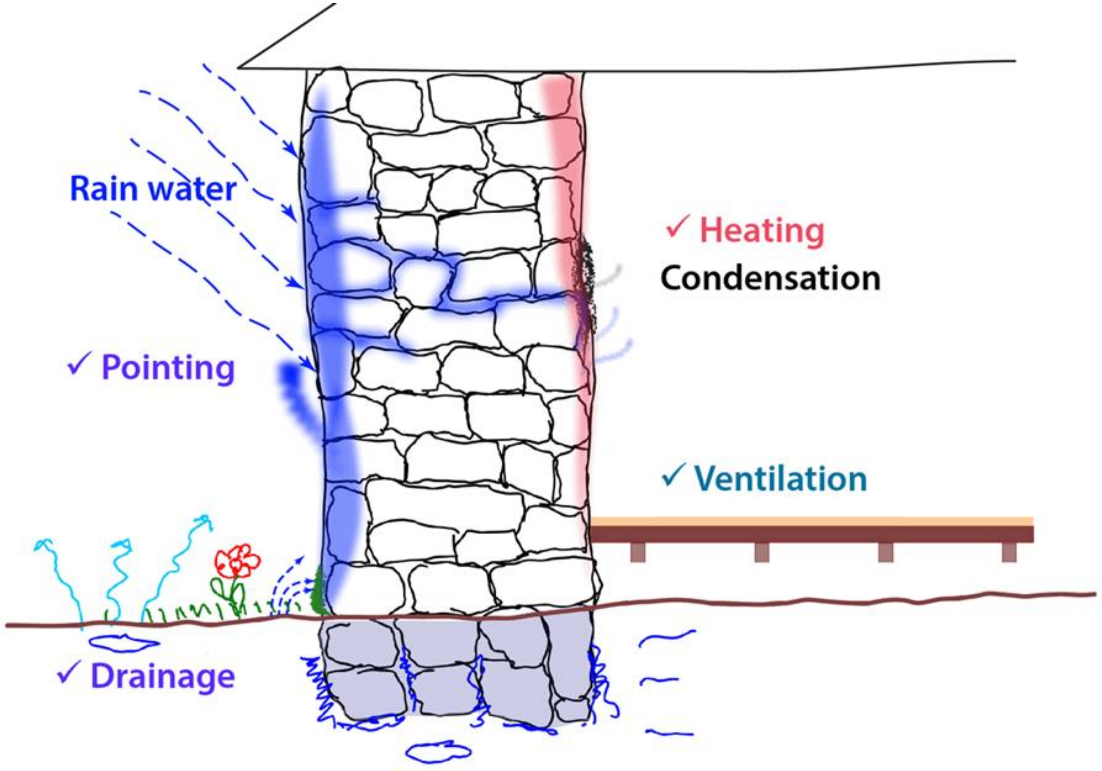
SOLUTIONS

- As a result, solutions to make old buildings dry, attempt to fix these 2 moisture sources. Most common actions:

1. **Rainwater ingress**:
   - Fixing all leaks
   - Tight pointing / Better detailing
   - Using breathable materials (lime etc.)
   - Avoiding non-breathable materials or moisture barriers (cement, plastics etc.)
   - Drainage
2. **Condensation**:
   - Heating
   - Ventilation

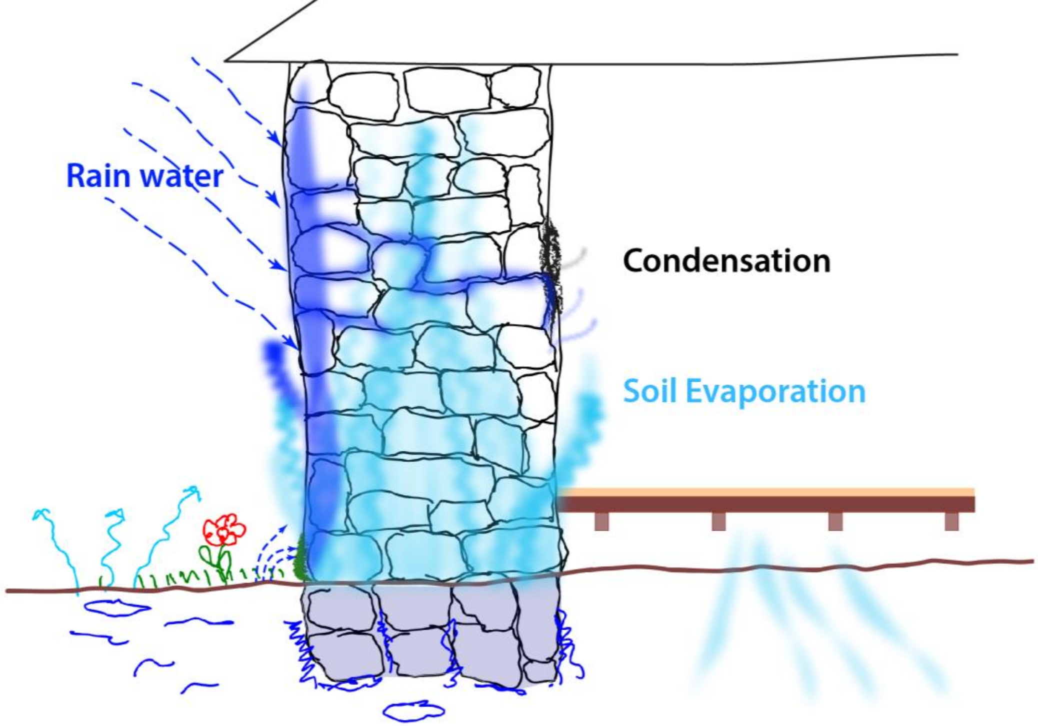
- Solving these problems should solve all dampness problems.

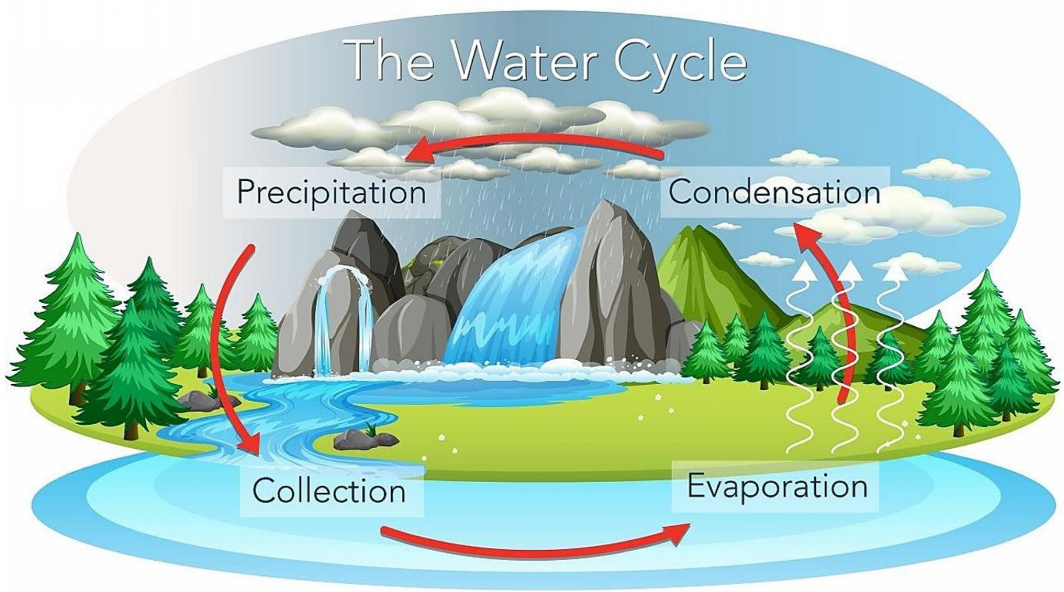
- This is often not the case. Some dampness problems mysteriously **persist and re-appear after some time** – despite all above efforts to solve them, especially in larger buildings with solid walls.
- Why? Because of soil evaporation.



THE 3RD MOISTURE SOURCE: SOIL EVAPORATION

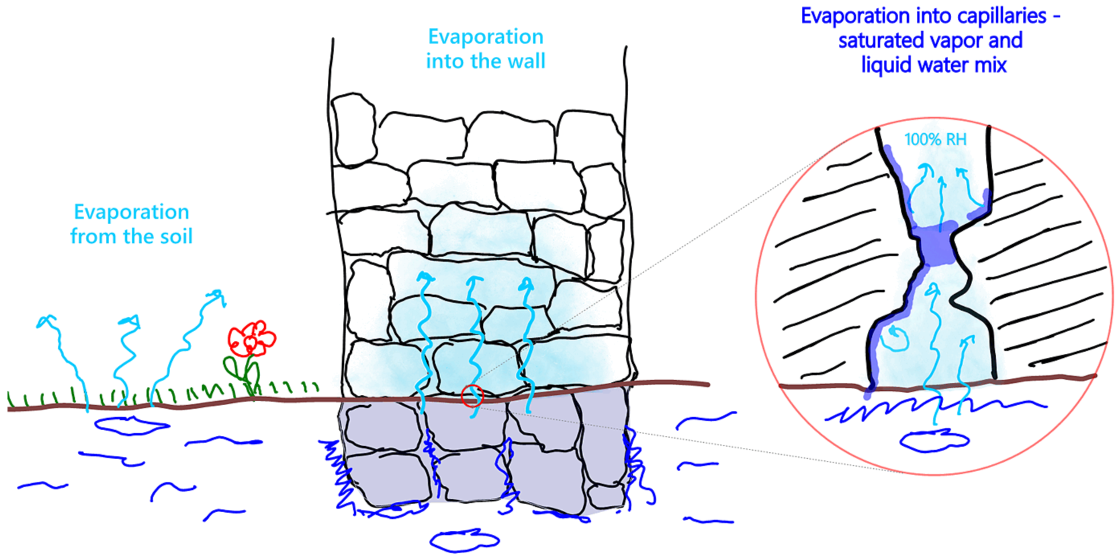
- Our research discovered that there is a 3rd "hidden" moisture source: **soil evaporation**.
- **Water Cycle**: describes the large-scale movement of water in nature:
  - Rainwater falls to the ground, goes into the soil
  - Vapors evaporate, rise up.
- The soil constantly (24/7) evaporates vapours.
- If a wall is built onto the soil, evaporation from **under the wall** will take place into the wall fabric. The full moisture path is: **Soil > Wall fabric > Air**
- Why did soil evaporation, as a moisture source, remained hidden? For several reasons:
  1. **Invisible**: unlike liquid water, vapours are invisible
  2. **Slow**: problems created by vapour migration build-up slowly
  3. **Easily overridden**: any other dampness problems (e.g. liquid moisture sources: *leaks, ingress* etc. often present) or repair works (*replastering*) override / hide it for months or years.

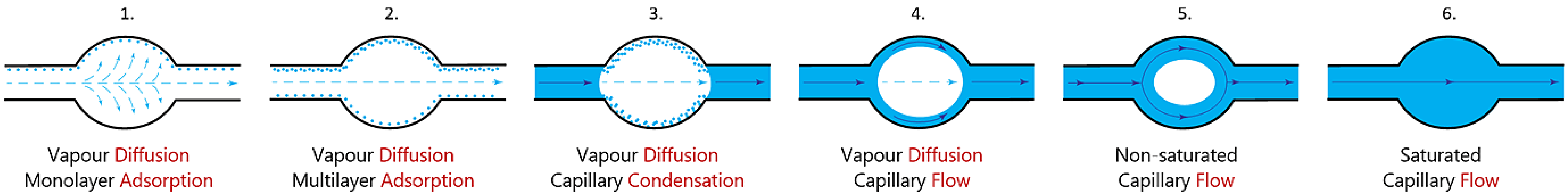




SOIL EVAPORATION

- Soil evaporation is a **standalone wetting mechanism**, does not depend on other moisture sources (rainwater ingress, condensation).
- Soil evaporation ***is*** the mysterious and eluding rising damp that confused so many.
- Its fundamental mechanism is **vapour rise *not* capillary action**. However, it can lead to liquid moisture accumulation and movement through **several stages**, capillary action being at the very end.





HISTORICAL CONTEXT

- Rising damp is widely known to be caused by **capillary action**. This is not correct simply because buildings are built on liquid water (except Venice) but on moist soil where it can't be capillary action.
- The idea of *rising damp = capillary attraction* appears in several period documents as early as 1844.
    - 1844: The Builder Magazine
    - 1863: Papers of the Royal Institute of British Architects (RIBA)
- The mechanism of rising damp as capillary action has only been **assumed** but never researched. We believe this was a **historical mistake**.
- Bricks subject to liquid moisture (capillary action – *fast wetting*) can look very similar to bricks subject to rising damp (through vapour accumulation - *slow wetting*) – both looking wet.

The Builder.

VOLUME II.

or alum may be added to the plaster in the first instance. When dampness arises in the walls by capillary attraction from the foundation, it resolves itself into a question altogether different; but, in the majority of cases, the

By John Taylor, Junior, Esq., M.A., F.S.A.

Read at the Ordinary General Meeting of the Royal Institute of British Architects, January 12, 1863.

We are all well aware of the difficulty of constructing dwellings which shall be free from damp. I propose, therefore, to consider how this defect may be remedied, and shall treat this matter under the three following heads:—Firstly, How to keep down ascending wet; Secondly, How to keep out drifting wet; Thirdly, How to shelter from falling wet.

The greatest evils, in a sanitary point of view, are doubtless caused by damp rising up the walls by capillary attraction. Rain, absorbed as it falls from the heavens, is uncomfortable enough; but

Prevention of Damp.—Having thus taken care that the air and moisture shall have no chance of rising into the house from the ground beneath the floor, we must now turn our attention to the walls, which it is equally necessary to protect from rising damp. If you plant a brick or stone wall on ground which is capable of retaining moisture, it will inevitably happen that unless you take means to stop its progress, the moisture will climb

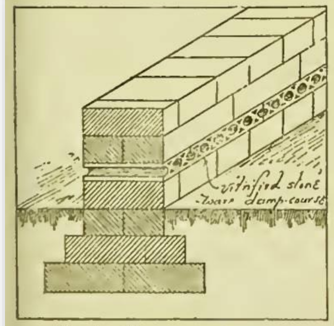
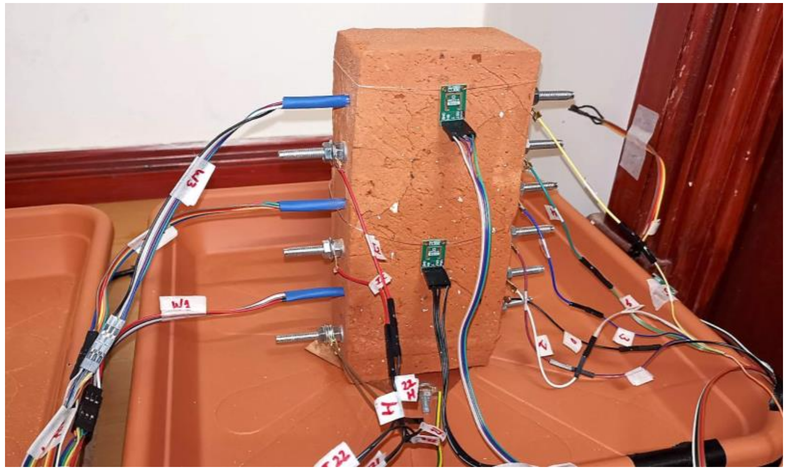


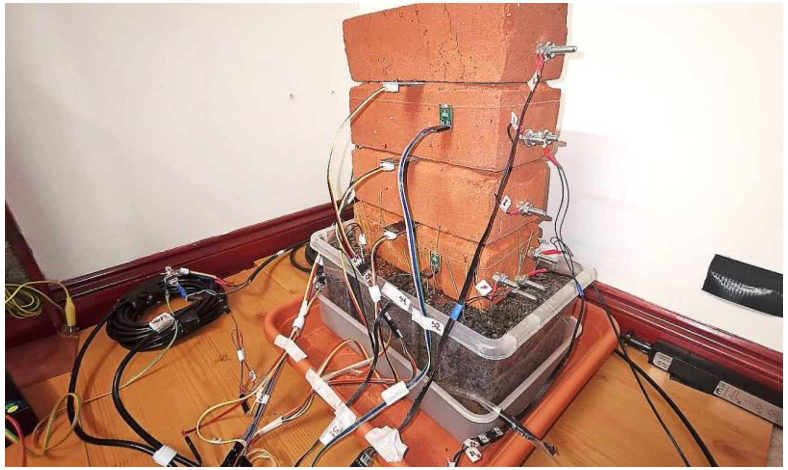
Fig. 1. Damp-proof course.

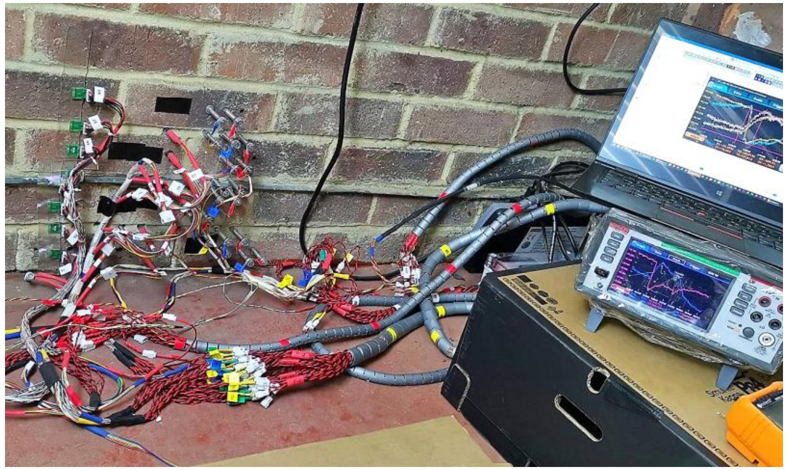
HOW DID WE DISCOVER / IDENTIFY IT?

- Went back to basics: 1 brick.
- **Lab experiments**: in strictly controlled environment (well heated, well ventilated, non-condensing).

  We built test walls using new old-style porous bricks and monitored the **full wetting-drying cycle**.
- We monitored the migration of moisture to understand:
  - How walls get wet and dry out?
  - To identify main stages
  - What additional phenomena accompany the movement of moisture?
- **On real buildings**: all findings verified during both summer and winter.







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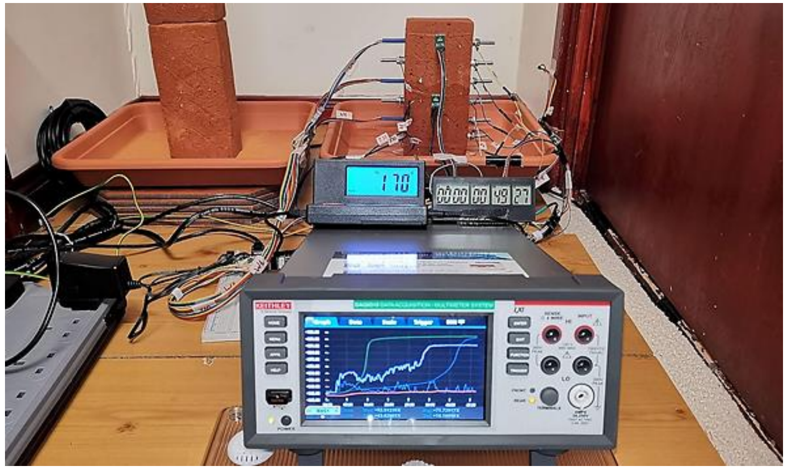
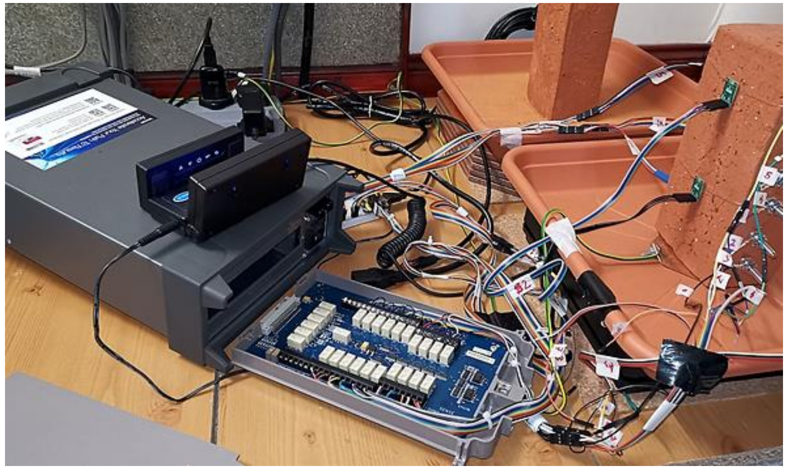
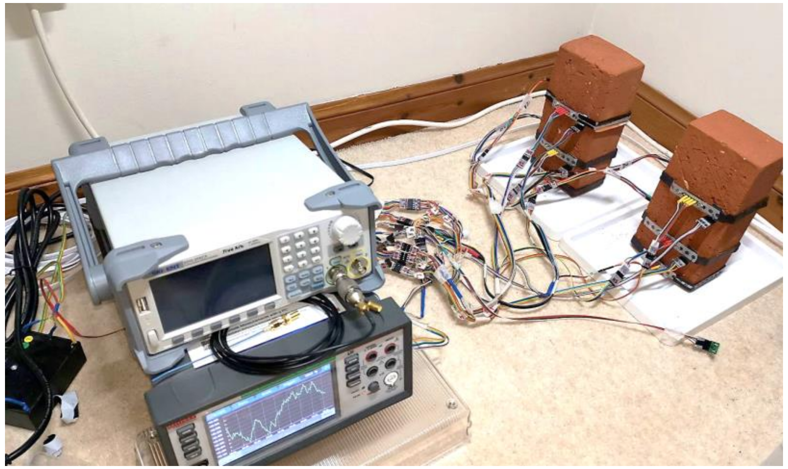
RESEARCH EQUIPMENT

- Readings taken with a Tektronix-Keithley 80-channel professional data logger: 0.0025% accuracy (error)
- Fast multi-channel data logging in real-time
- Virtually every type of sensor can be interfaced with it.
- Data can be exported to Excel and other software for further processing and charting.
- Readings:
  - **Hygro-thermal** readings: temperature, RH (soil, surface, depth, ambient), pressure. Calculated: absolute humidity (g/m^3), dew point temperature
  - **Electrical** readings: voltages, currents, resistances, capacitances, magnetic-fields (accompanying phenomena)







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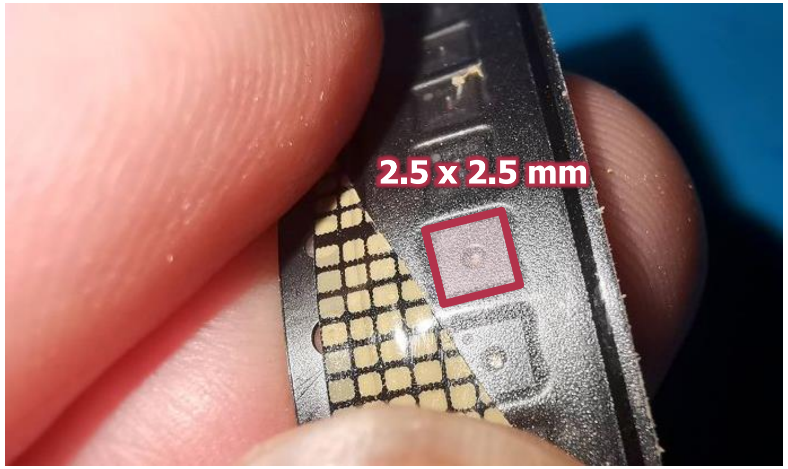
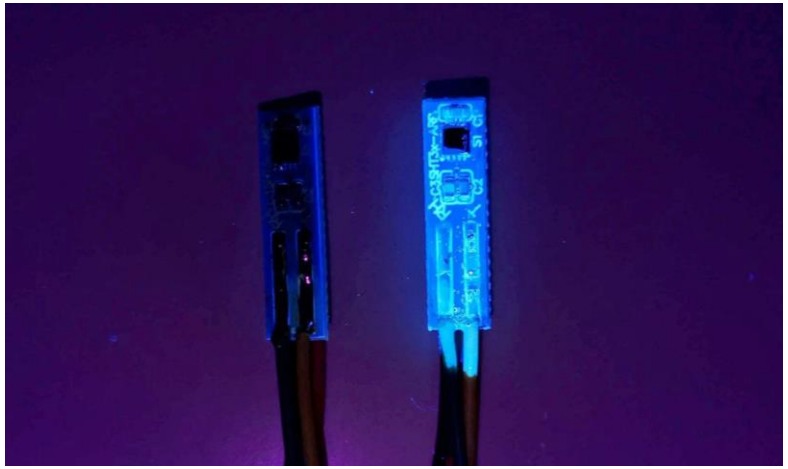
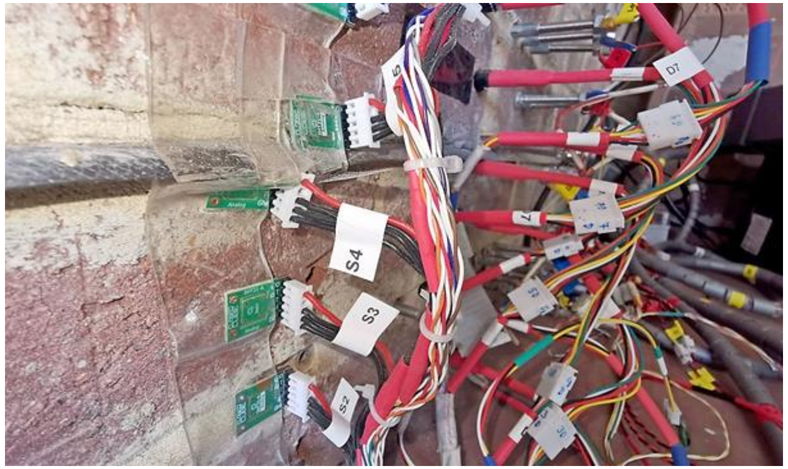
SENSORS

- We built our own sensors.
- Commercial sensors are:
  - Too large, won't fit inside the wall
  - Not sensitive enough
  - Not integrated into a system
  - Not scalable enough: from a few to 100s of sensors
  - Data logging / export limitations
  - Often expensive
- This gives us full control over all technical parameters.
- We record tens of parameters of the wall fabric in real time.
- Scalable to over 2,000 sensors, if needed, making large-scale complex monitoring projects possible.
- Live data can be "pushed" online for real-time viewing and monitoring.







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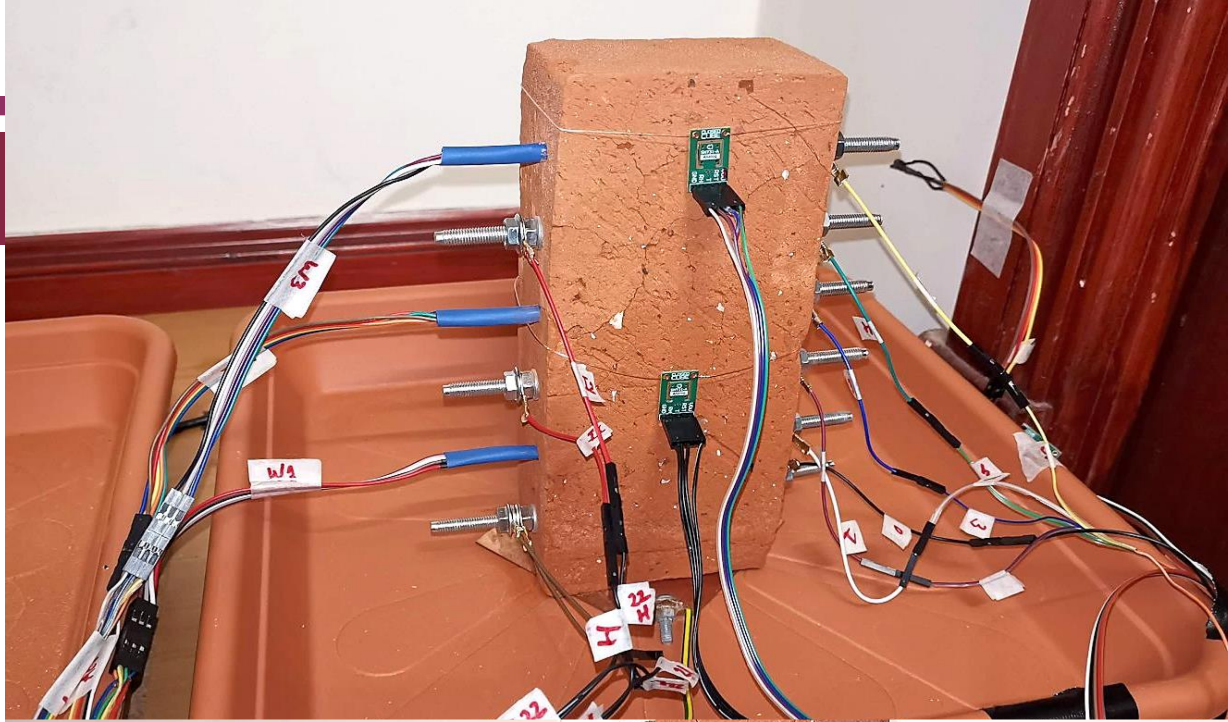
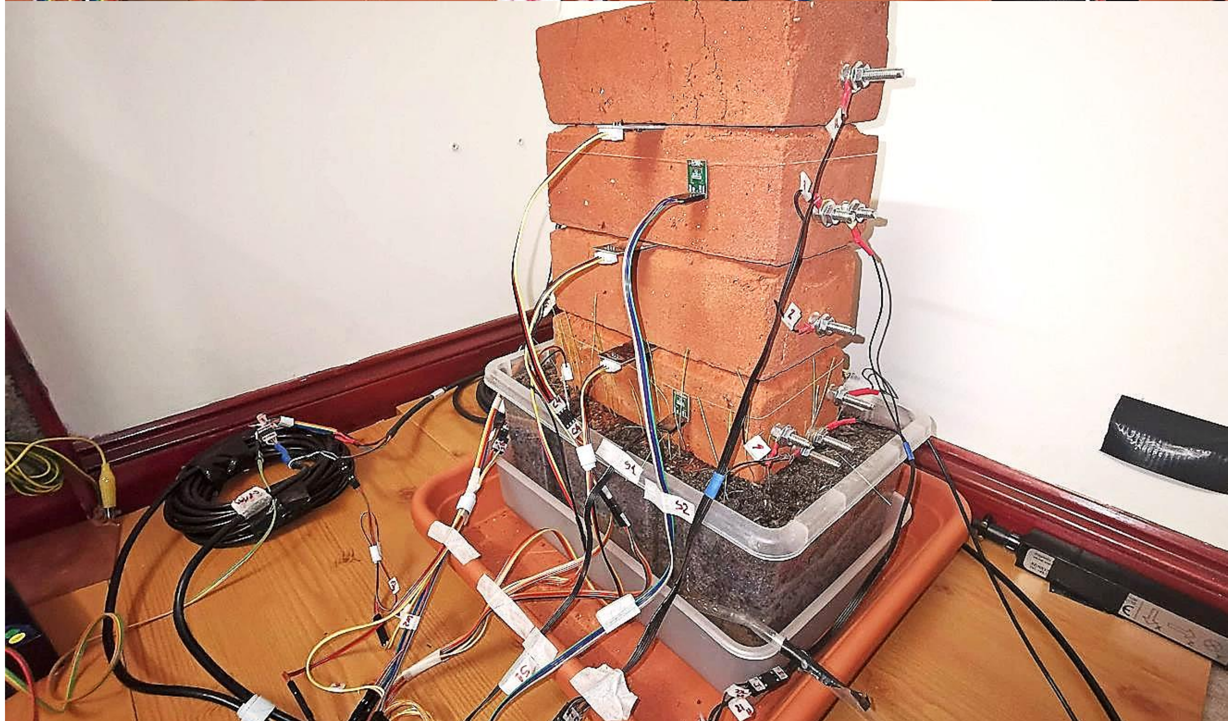
EXPERIMENT – FAST VS SLOW WETTING

- Several experiments, two fundamental setups:
  - **Fast wetting**: single brick in tray subject to liquid moisture
  - **Slow wetting**: simulating rising damp from the soil (water table variations after rain). Bricks placed on well drained but moist soil. Wetting controlled from the lower second tray.
- Brand new, dry old-style porous bricks used, same batch
- Condensation free, sheltered environment, in thermal equilibrium
- Before looking into the findings, we need to introduce some important phenomena accompanying the movement of moisture: **electrical charge migration** in damp masonry

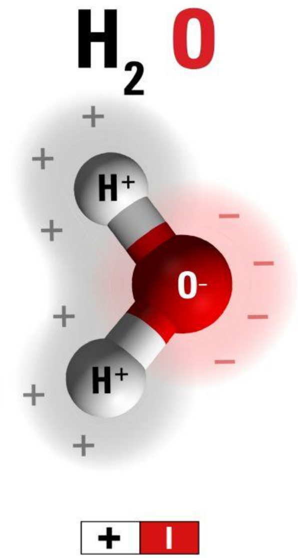


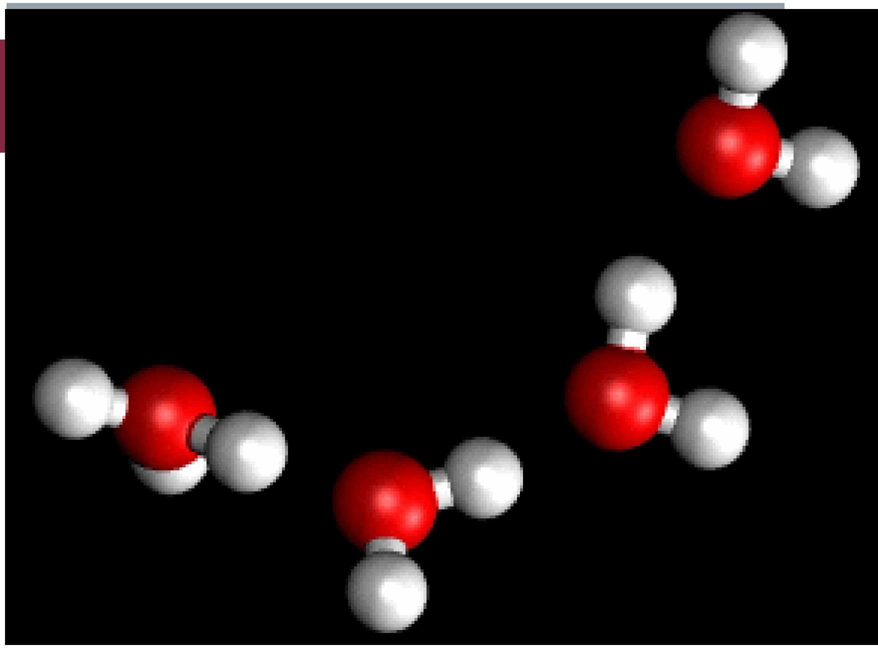


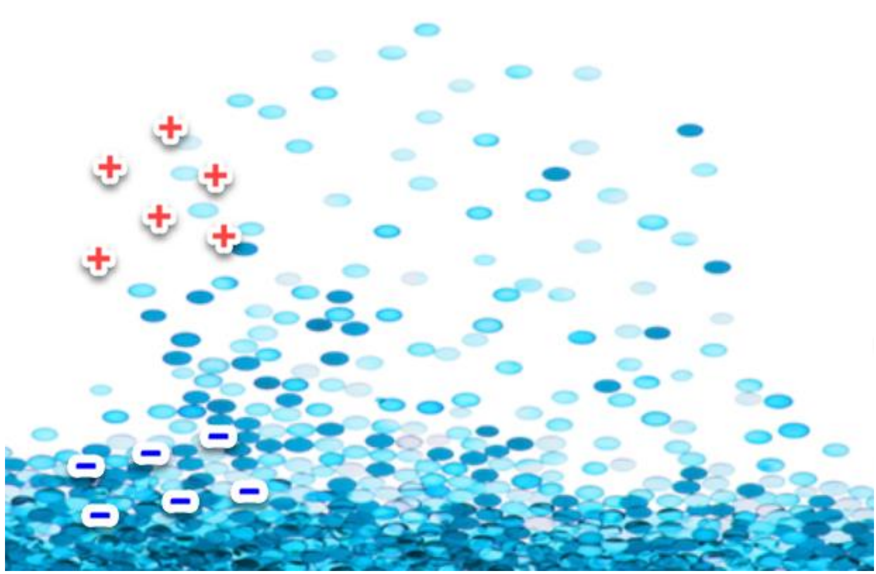
ELECTRICAL CHARGE MIGRATION IN DAMP MASONRY

- A very important technical discovery about damp walls: **humidity movement in a damp wall fabric always generates electrical charges**.
- Why? Because of anatomy of water molecules (H_2O):
  - They are polar molecules (charged).
  - They don't have a fixed structure.
  - They are connected by <u>very weak temporary bonds</u> (hydrogen bonds) that constantly break and reform, forming random connections with neighboring molecules.

    This is known as "proton hopping": H^+ ions (protons) constantly jump between neighboring molecules, leading to **charge separation and migration**.
  - H^+ ions: the smallest particles in water, main charge carriers.
- When water evaporates, the fast H^+ ions "jump" through the liquid surface, making vapours positive.
  - **Water vapours** (excess H^+) are thus always **positively** charged
  - **Liquid water** (shortage of H^+) are **negatively** charged.
  - A **dry fabric** has **no charges**, it is electrically neutral.



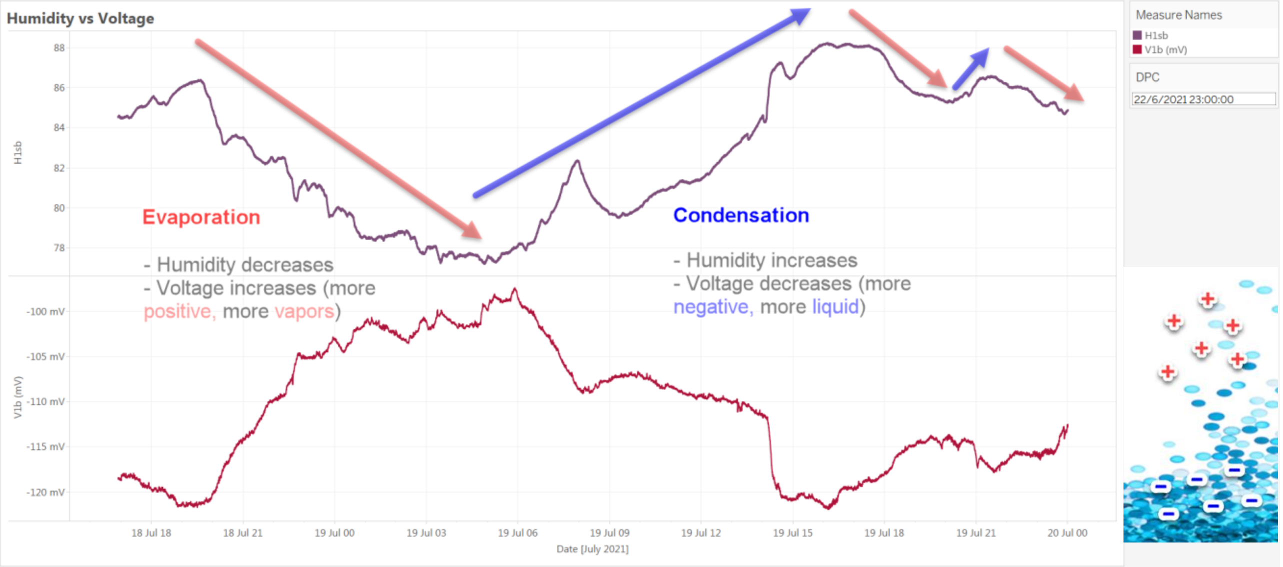




ELECTRICAL CHARGE MIGRATION IN DAMP MASONRY

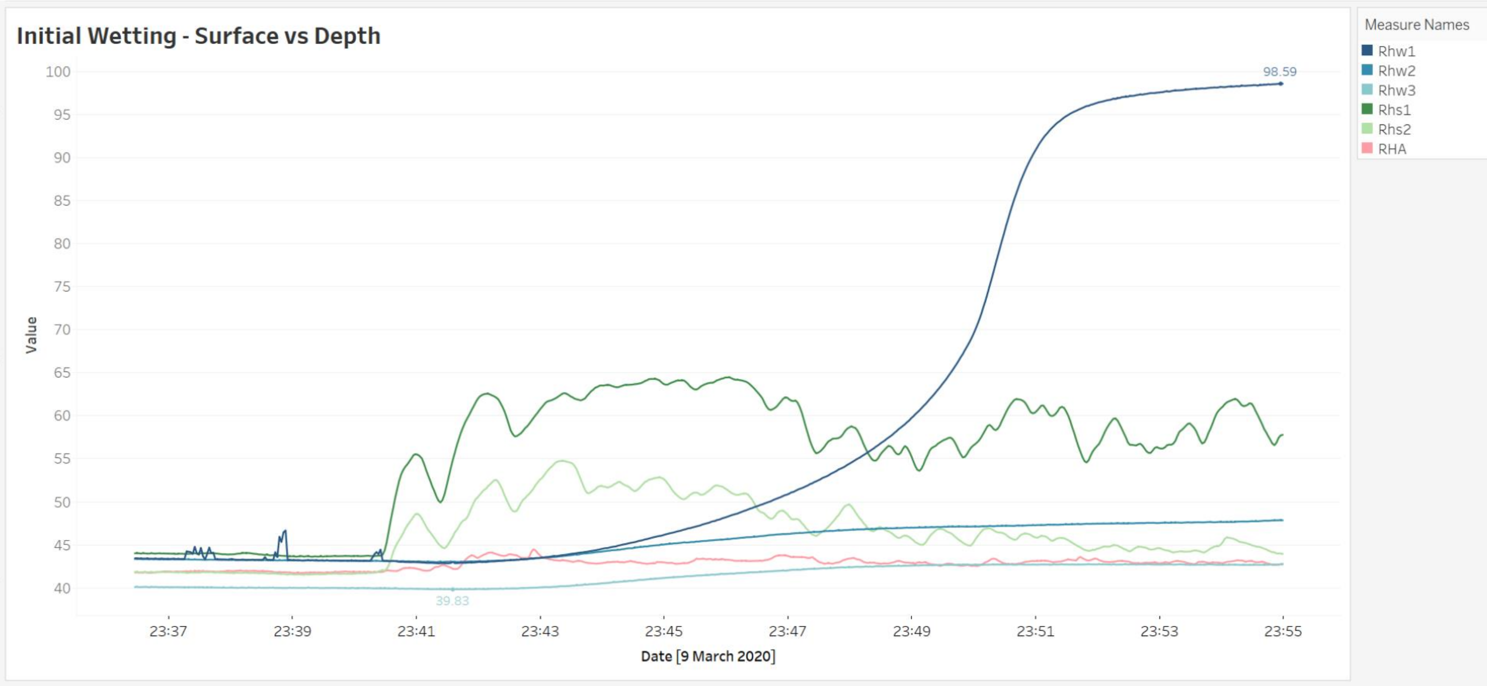
- These charges in the wall can be demonstrated with a simple multimeter.

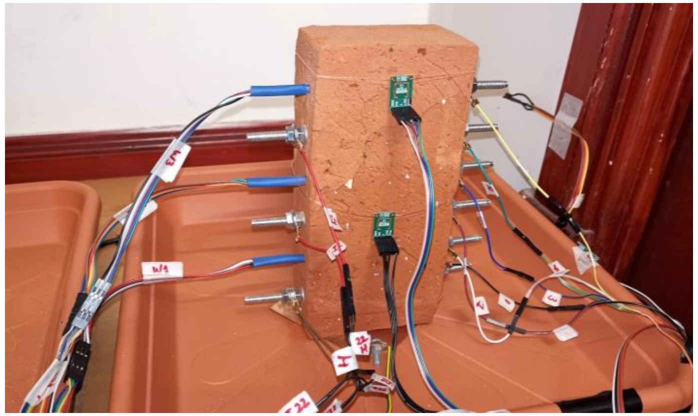
- Some examples: humidity (RH graph) mirrors the voltage (V) in the wall very closely.
  - Subsequent evaporation / condensation cycles:
  - Evaporation: more vapors, voltage increases
  - Condensation: more liquid, voltage decreases
- Electrical charges and humidity **ALWAYS** go together, they are **inseparable**. As the wall humidity changes, the V also changes, second-by-second >> Potential new diagnosis method.
- Back to our experiment

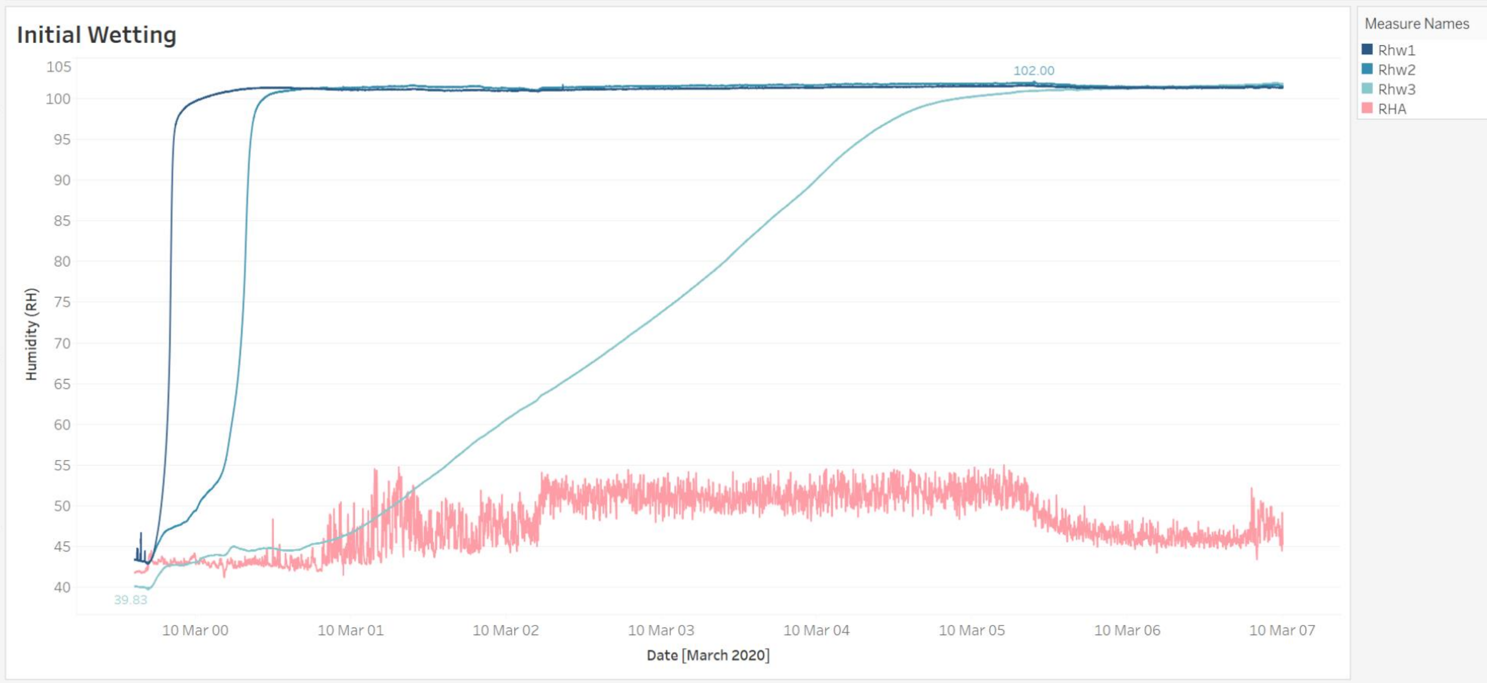


FAST WETTING – SPEED OF RISE

- **Fast wetting**: the liquid waterfront rises, reaching the sensors one-by-one
  - 1st depth sensor: 11 mins
  - 2nd depth sensor: 40 mins (halfway)
  - 3rd depth sensor: 6 hrs (top of the brick)

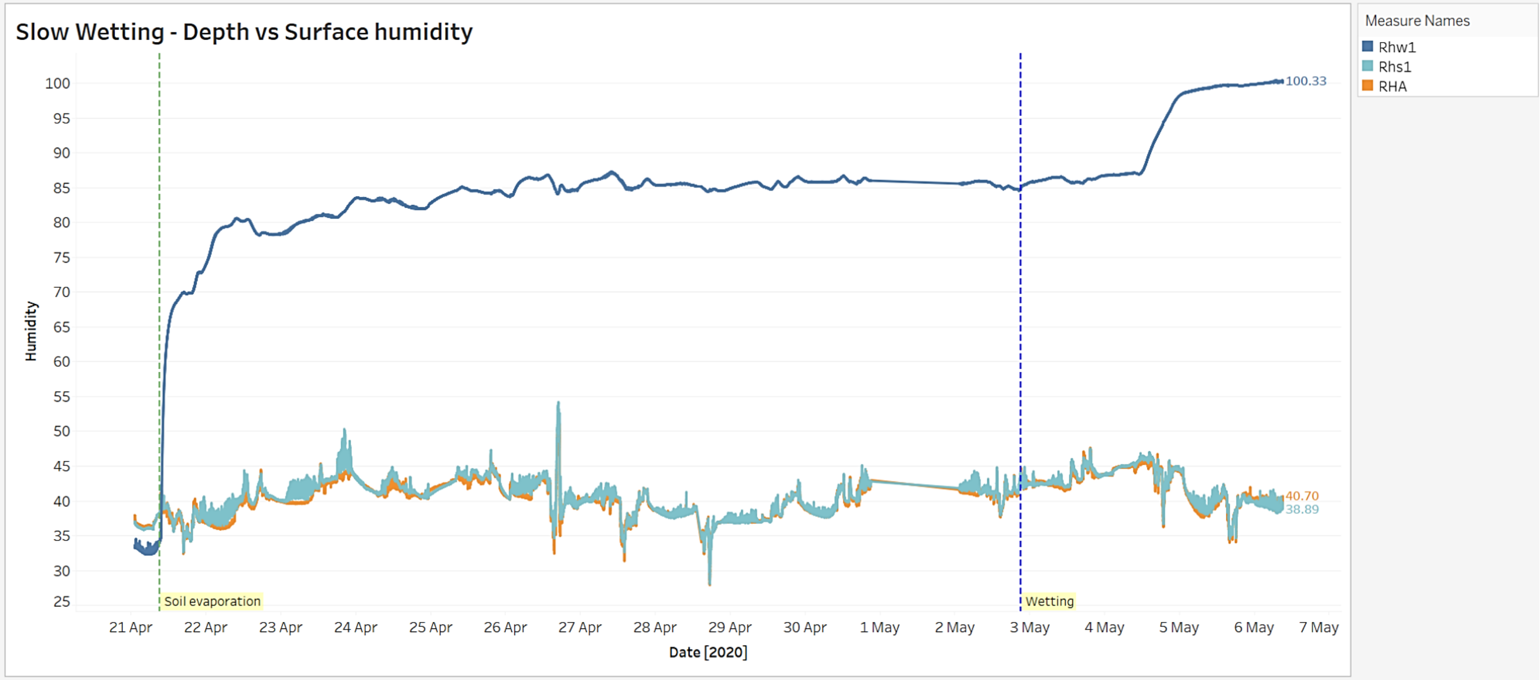






SLOW WETTING – SPEED OF RISE

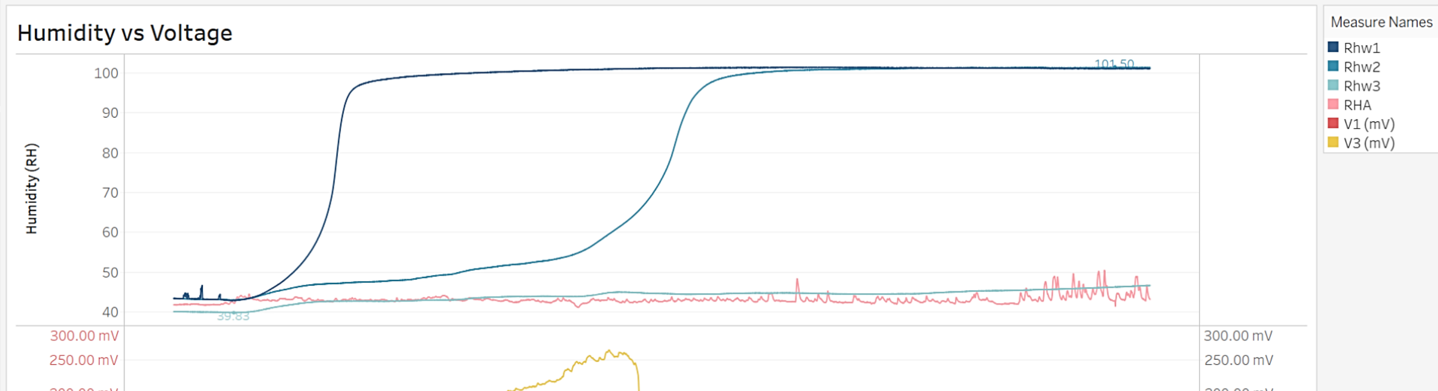
- **Slow wetting**: bricks on soil
  - No liquid waterfront.
  - Only moisture source is soil evaporation (from a well-drained moist soil) .
  - Much-much slower process.

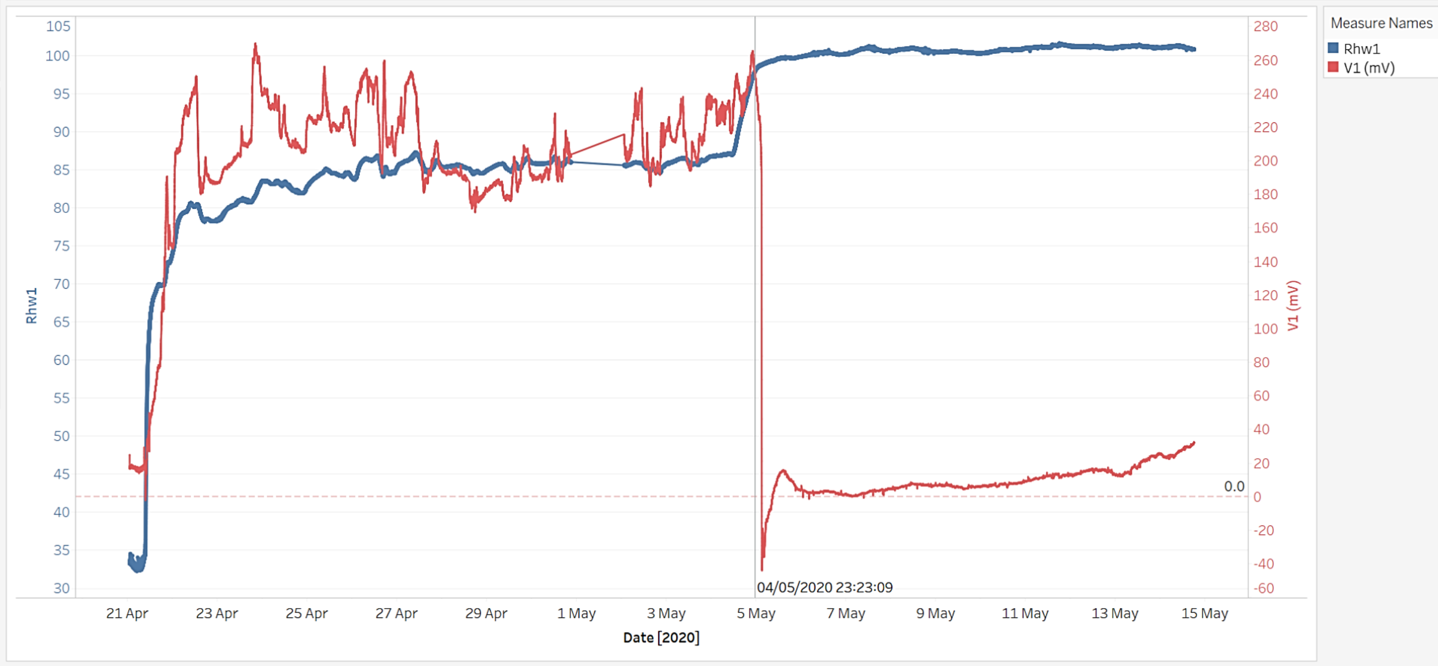


- Timing
  - 1st depth sensor to reach 100% RH: 14 days (20,160 vs 11 mins) ~ **2,000 times slower**!

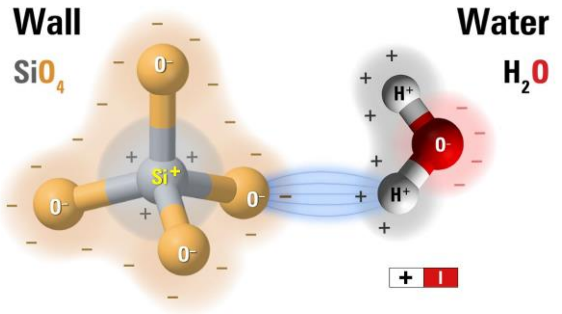
SAME PHENOMENA

- Fast and slow wetting have the same accompanying electrical phenomena:
  - Notice the **sudden voltage drop** every time the humidity reaches 100% RH
  - Voltage maxes out then drops to negative
    - Indicates saturation: **vapour turns into liquid**
    - Saturated vapors into liquid moisture.
- Time to saturation (1st depth sensor)
  - Fast wetting: 11 mins
  - Slow wetting: 14 days (21 April – 5 May)
- Voltage drop speed
  - Fast wetting: 30 sec
  - Slow wetting: ~ 12 mins

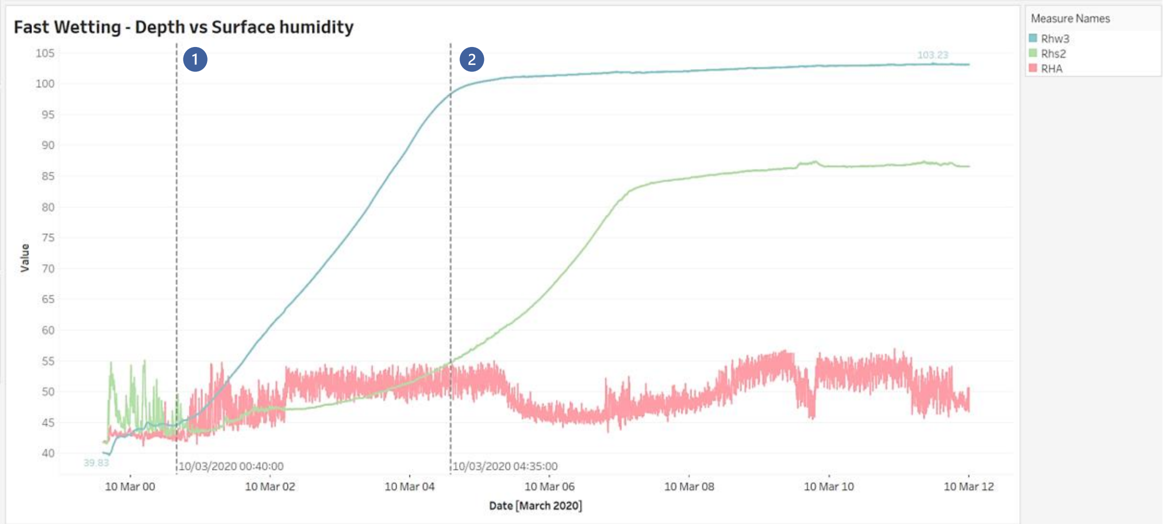


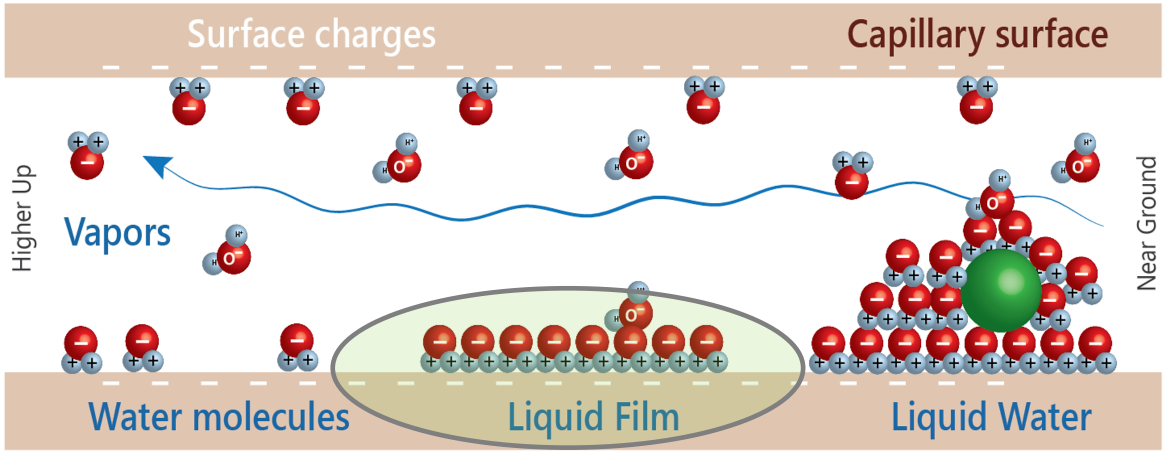


PRACTICAL IMPORTANCE OF ELECTRICAL PHENOMENA



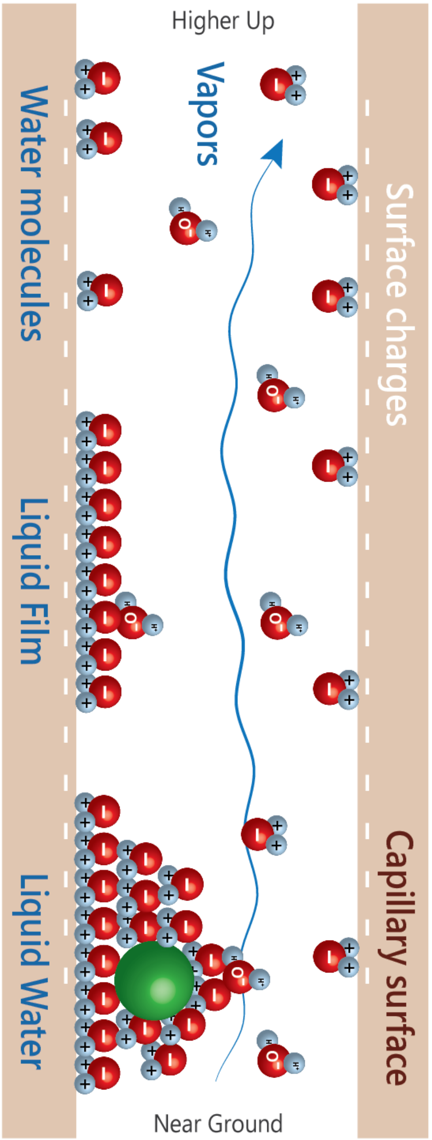
- **Why are electrical phenomena important?** Because they directly affect the fabric's breathability. How?
- Breathability is a 2-stage process. When a dry brick comes in contact with the damp soil, 2 distinct phenomena occur:
  - **Stage 1: Moisture accumulation**: vapours are attracted to and bond to capillary surfaces, gradually neutralizing the wall's surface charges, then
  - **Stage 2: Evaporation**: the decreased surface charges allow evaporation to start and vapors to "float-through" the wall into the surrounding air.
- Surface charges: are electrostatic attraction forces between water molecules and capillary surfaces
- What this means?
  - In a perfectly breathable wall fabric (with no moisture barriers) surface charges make **moisture accumulate**.
  - Hence, **a perfectly breathable wall fabric is not dry**, but contains quite a bit of moisture.
  - Some of this moisture is used to cancel out the surface charges so evaporation could start.





WETTING PROCESS - SUMMARY

- The wetting process step-by-step – how rising damp builds up
  - Vapors rise from the ground, evaporating into the porous building fabric (capillaries).
  - The “free-flying” water molecules are attracted by surface charges to capillary surfaces.
  - An accumulation of moisture occurs, resulting in gradual wetting.
  - Some water molecules deposited onto capillary surfaces neutralize the surface charges, making possible for subsequent vapors to “fly through” the capillaries and evaporation to start.
  - Once a thin liquid film is built up on the inner face of capillaries, salt migration starts, which results in further moisture accumulation.
- There are still open questions here, but research is ongoing. For e.g.
  - Data indicates that surface charges are not fixed, but variable and they can be changed – e.g. by changing various parameters of the environment.
  - Reducing the surface charges decreases capillary bonding, making the wall fabric “let-go” some of its accumulated moisture, becoming more breathable and thus drier.
  - Increasing the surface charges increases capillary bonding – less breathable and damper fabric.
- Lot more new research data on heating (role, effect, limitations), condensation, evaporation, other electrical phenomena accompanying moisture movement etc.
- New findings are being documented and published in (future) research papers.



PUBLISHED PAPER

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- Published paper: Best Paper Award nomination

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Electrical Effects during the Wetting-Drying Cycle of Porous Brickwork: Electrical Aspects of Rising Damp
Sandor Levai, Valentin Juhasz, Mick Gasz

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Electrical Effects during the Wetting-Drying Cycle of Porous Brickwork: Electrical Aspects of Rising Damp

Authors : Sandor Levai, Valentin Juhasz, Mick Gasz

Abstract : Rising damp is an extremely complex phenomenon that is of great practical interest to the field of building conservation due to the irreversible damages it can make to old and historic structures. The electrical effects occurring in damp masonry have been scarcely researched and are a largely unknown aspect of rising damp. Present paper describes the typical electrical patterns occurring in porous brickwork during a wetting and drying cycle. It has been found that in contrast with dry masonry, where electrical phenomena are virtually non-existent, damp masonry exhibits a wide array of electrical effects. Long-term real-time measurements performed in the lab on small-scale brick structures, using an array of embedded micro-sensors, revealed significant voltage, current, capacitance, and resistance variations, which can be linked to the movement of moisture inside porous materials. The same measurements performed on actual old buildings revealed a similar behavior, the electrical effects being more significant in areas of the brickwork affected by rising damp. Understanding these electrical phenomena contributes to a better understanding of the driving mechanisms of rising damp, potentially opening new avenues of dealing with it in a less invasive manner.

Keywords : brick masonry, electrical phenomena in damp brickwork, porous building materials, rising damp, spontaneous electrical potential, wetting-drying cycle
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ANY QUESTIONS?

THANK YOU.

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