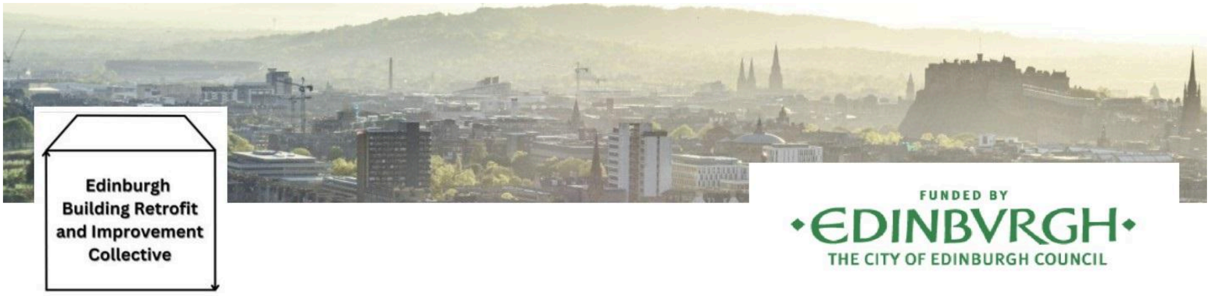

Insulation vs Ventilation etc: How buildings 'work' in relation to retrofit

Presentation Slide-by-Slide Script

A presentation by Jon Stinson PhD, academic, researcher and Director of Building Research Solutions Ltd. As presented at an event hosted by Edinburgh Building Retrofit and Improvement Collective (as part of Climate Fringe week) on 13/06/2023. His more specific title was 'Applied Building Physics: the application of science to energy efficiency retrofit'.

This transcript may not be exact, but is taken from the detailed slide notes created by Jon.

Title slide:

Hello everyone.

I'm very pleased to be here, and speaking with you all, this evening. Albeit, via the power of the internet.

Thank you to the **Edinburgh Building Retrofit and Improvement Collective** for, firstly organizing and hosting an event like this. More of this is sorely needed.

But also thanks to them for inviting me to speak with you all this evening. They've done an amazing job at organizing all of this.

And thank you to you for taking time out of your schedules to be here.

I want to start off with ….

'Why listen to Jon & BRS' (1)

Why should you be listening to me? This isn't an attempt to promote Building Research Solutions. Rather, these next few slides are here to qualify me to speak on the topic, and to reassure you that you've made a good choice by choosing to be here tonight.

BRS or building research solutions, is effectively broken into 2 parts, my business partner Ruth leads the whole life cycle and embodied energy and carbon R&D side of the company. And I lead the operational energy and carbon R&D side of the company.

Which simply means, I lead our projects that focus on energy use in a building, when the building is being occupied. Ruth leads on projects that focus on the energy and carbon required to create materials, transport them, construct with them to create the building or retrofit project, then she investigates the end-of-life scenarios for those materials, after the building reaches the end of its life. This includes the recycle and reuse principles inside the circular economy theory.

Both of us effectively spun out of Edinburgh Napier University's Institute for Sustainable construction, in 2020. Ruth left the resource efficient built environment lab research centre, and I left the Scottish Energy Centre. And have since be appointed as regional chair for the Chartered Institute for Architectural Technologist (Scotland East region).

Both of our academic research centres were applied science centres, which meant that all of the projects we worked on were industry led, and industry focused. Now, we at BRS continue to support the people and organisations that are effectively supporting you. so, for retrofit our clients are typically architectural designers, retrofit installers, material manufacturers housing associations, housing cooperatives etc.

So, whilst we work with all types of buildings, projects, and methods of construction, we have a long history with existing Scottish buildings ….

‘Why listen to Jon & BRS’ (2)

… Especially the traditional/historic/pre 1919 variety.

Over the last 13 years, I’ve personally crawled through attics, on top of roofs, through basements and solems, to add every type of sensor to every conceivable location, all in the name of science and building physics.

This is what used to be called retrofit building performance assessment and evaluation, which is now often referred to as retrofit assessment and retrofit evaluation. But be careful with those new terms, because they are grossly slimmed down versions of the original building performance version.

We’ve used lots of different hardware, including loggers, sensors for temperature, relative humidity, moisture content, air movement, heat flow, infrared imagining devices, low pressure and high pressure air permeability apparatus, 3d lidar scanning technology. And we’ve assessed and evaluated the pre and post retrofit hygrothermal performance of buildings right across Scotland.

From Uist to Rothesay, Cupar to Edinburgh, and all along the Central Belt.

Most of which was funded by Historical Environment Scotland …

‘Why listen to Jon & BRS’ (3)

As such, I’ve either directly published or provided the scientific data and results for the publication of the first 10 refurbishment case studies, and 4 technical papers on retrofit methods.

All the early work that we delivered to Historic Scotland (now called Historic Environment Scotland); I and my colleagues at Napier, launched the retrofitscotland.org knowledge exchange portal. We built that with Architecture and Design Scotland, BRE Scotland, and HES. All of my research on retrofit methods was used to launch the first wave of case studies on that site. Sadly, that site died around 2017 – 2018. which is a shame.

Terminology check: the 5 Rs

Last thing. Before I properly start, I want to do a quick terminology check.

You’re going to hear me say the word ‘retrofit’ a lot. Here is what I mean by retrofit:

To add additional, or replace existing, materials and/or technologies with ones which will improve the building’s energy efficiency. These relate to insulation materials and energy generation systems and can relate to those that conserve water.

Words like renovate and refurbish appear to be used interchangeably with retrofit. But they do mean different things.

Ultimately, it doesn’t matter what definition of word you us, as long as you know what I mean, for the duration of this talk.

What I’ll be covering - Equilibrium and Balancing Environments

Now, into the actual topic of the talk.

I want to cover 5 topics:

1. Equilibrium and Balancing Environments – I want to start by taking a brief look at the fundamentals that govern building physics
2. Energy balance [gains and losses] – here I will do a quick break down of the types of thermal energy exchanges that are happening in our buildings. With a very simple example.
3. Water transfer and ventilation – here I'll explain how thermal energy relates to hygrothermal (which is the movement of both heat and water), and where ventilation plays in all of this.
4. Data capture: inform Energy Efficiency retrofit – here I'll start to bring the talk to a close.
5. Whole building EE retrofit measures. For time's sake, I'm only going to cover thermal fabric retrofit measures.

I'm going to try and keep all of that to below an hour. Whilst I can, and have spoken continuously on this topic for hours, it can be a lot to absorb, decompress, and consolidate to a point that it makes sense to you. So, I want to leave a good amount of time for questions.

Last thing before I start, I must say, that I am covering topics that people have turned into 4 year university degree programmes, some – like myself – have dedicated 3+ year on PhD level R&D on this topic. I think Mick from BANZAI said it best: in the time available, I'll provide an overview of the technical fundamentals to help puzzle through energy efficiency and building performance uncertainties (but without the scary maths). So, the take-away messages for this are:

- understand why energy efficiency is not as simple as blocking every draught and insulating everything;
- how to gather actionable information for making informed decisions;
- understanding when an 'obvious choice' may benefit from careful consideration or requires expert advice;
- the right type of questions to ask your chosen retrofit professional
- understanding when recommendations may be based on poor understanding or insufficient knowledge.

Building Physics: Equilibrium

Right. Lets start with the fundamentals of Building physics.

I teach, and building physicists are taught, that the core of building physics is equilibrium.

Quite simply, this means the equilibrium of environments.

Within those environments, the conditions are in a constant state of flux. There is a constant balancing between thermal energy (or heat), water vapour, and air movement and we can think of those 3 things as conditions that define our environments.

So, the external environment is constantly in flux, because those 3 conditions are changing at various speeds or rates.

Building Physics: Equilibrium (2)

And when we create a building …

Equilibrium: balancing environments (1)

And by building I mean, we construct walls, roof, floor, and combine those together into a building, we are partitioning and enveloping a volumetric part of that external environment into a separate environment. Almost like a micro climate.

If that building remains unconditioned, then the internal **conditions will be very similar to**, - but lag behind –the action of the conditions in the external environment. This lag is usually in the range of a few minutes to a few hours, and the extremes aren't as high or as low in the internal environment as they will be externally. But, **importantly, the internal and external environments are in close equilibrium**.

And this lag happens because the walls, roof and floor act as a barrier to wind and precipitation, thereby reducing the effects of large swings in those conditions.

Then, when we introduce people into our building, we create a need to further reduce these conditional swings - in the internal environment's conditions – even further. So, we need to stabilise those condition, to create a more stable internal environment.

So, we artificially heat and try to cool this volume to compensate for what is happening outside. So, we've now created an **internal environment that is very different to the external environment.** So, the walls, roof and floor now take on a new role - they are the building's thermal envelope. And it's the thermal envelope's job to manage the environmental differential between the internal and external conditions.

Equilibrium: balancing environments (2)

Then, as we sub divide the volume inside our envelope and expose it to various temperatures and concentrations of water vapour, we start to create sub environments.

When environments are divided (which includes a physical division (i.e wall) and a conditional division (i.e. say a bathroom and bedroom which experience difference temps and RH levels) they work to balance any variations in temperature, air movements and water vapour across those physical divdivisions.

So each of our sub environments is now also in a constant state of flux. Each sub environment, inside the building, is trying to balance the temperature, air movement and water vapour across the indoor environment. And the whole internal environment is trying to balance with what is happening in the external environment.

So it's up to our building's Thermal envelope to buffer this balancing in a way that suits our agenda. Which is: circulating foul air (from concentrations of human existence) with fresher external air maintaining respiratory comfort (good indoor air quality), reducing the amount of fuel used to change the internal temperature from the external temperature to maintain thermal comfort, and preventing conditions for the germination of mycelium spores (fungi).

Equilibrium: balancing environments (3)

This fundamental part of building physics is agnostic to the type of building. So these principles apply to new build construction just as much as they apply to retrofitting of existing buildings.

The main difference is, and for the purpose of this talk, before you retrofit an existing building, its thermal envelope has been managing the internal conditions of that internal environment in the same way for the last 5, 10, 50 or 100 plus years. When you alter or add any material to that building's thermal envelope, you are fundamentally changing how that thermal envelope now manages and buffers the harmonisation of the internal environment to the external environment.

Now, Let's now look at heat balancing across our building's thermal envelope…

What I'll be covering – 2: Energy balance

Right, let's move on to the specific conditions that make up are environments.

We'll start with energy balancing, and by energy I'm specifically referring to thermal energy. So, heat.

What is Heat Balancing

The first thing to note is that we are talking about heat, which is a form of thermal energy.

And like all energy exchanges, when heat energy enters or leaves a system, it transfers through the line of least resistance.

Think of heat like electricity, and we know that electricity will jump around insulators to connect with other conductors. And heat and in fact water vapour movement, behaves in a very similar way.

Thermal energy balance: gains & losses

So, balancing is looked at from the perspective of reducing active heat generation – which is to say: reducing the amount of heat generated from a boiler or heater.

With that in mind, balancing means to minimise the heat losses through the building's thermal envelope and maximise the heat gains.

This is known as passive heating. If you are familiar with the Passivhaus or EnerPhit movements, then this balancing to minimise losses and maximise gains, is the founding principle Passivhaus.

But it is not the exclusive to the Passivhaus movement. It's the basis for all building physics.

Thermal energy balance: heat loss (1)

So, for heat losses, we can categorise these into three groups.

Planar heat loss: is heat loss through internal surface areas of our thermal envelope. so that means the temperature difference through the walls, ceiling, floor, closed windows and doors of our homes.

Bridging heat loss: is similar to planar. But bridging is the temperature difference through junctions, corners, and joints - at the points where our planar elements change. So, for example, the corner between a ceiling and wall, or the joint between a wall and window.

Ventilation heat loss: is most likely the one that we're all familiar with. Because we'd call it something like 'a draught'. And because of that, ventilation heat loss is often seen as being a bad guy – meaning, that ventilation heat loss is almost always incorrectly considered as something that we must stop, rather than something that needs balanced to maintain an adequate rate of air change to maintain good indoor air quality.

But we'll come back to air movement in a few moments. **[and we will talk about regulated and unregulated ventilation heat loss]**

Thermal energy balance: heat loss (2, table a)

I wanted a cool little infographic here, but this matrix was the best way to articulate this next piece of information.

So, on this slide and the next one, I've got something of a cheat sheet on how to think about and consider these 3 heat loss pathways.

For planar, it is a function of surface area, and it is what the construction industry will call a U-value or thermal transmittance value. Be careful, because I've seen websites, blogs, and articles – even those from official construction companies, use the phrases thermal conductivity or thermal resistance when they meant thermal transmittance. Those 3 are related but they aren't interchangeable.

Bridging is a function of a linear length – like the length for the junction between your wall and floor. This is often called thermal bypassing. And this has two metrics, 1 is called a psi value the other is a temperature factor. Temperature factor is an indication for the risk of surface condensation.

Ventilation heat loss is a function of the home's internal volume. This one has a whole host of different names and units of measures. But essentially. It is measured as either air changes per hour, or air permeability through the building's thermal envelope.

Thermal energy balance: heat loss (3, table b)

Planar U-values are calculated, by designers or retrofit installers, using software. This, like almost all calculated values, they can be measured by building performance evaluation hardware. The way to improvement planar heat loss – or the U-value – is to add Insulation layers to the elements. And we talk about these in a few moments. But these are things like internal wall insulation, ceiling insulation, secondary glazing etc.

Bridging heat loss, or psi values and temperature factor, are calculated in much the same way as U–values, using specific software. Temperature factors (but not psi values) can be measured using an IR camera, and surface temperature sensors. The way to improve the bridging heat loss is to ensure that the planar insulation overlaps between elements. That is easier said than done for existing buildings. Which means the bridging part is usually overlooked, but you should know that they must, at the very least, be considered. So, this is something that you can raise with your chosen construction professional when the time comes to retrofit your home or building with thermal materials. And in flatted dwellings, that is usually the time to involve your neighbours. Because, if you're adding any insulation, you want it to wrap around as much of the thermal envelope as you can. And this might include your neighbour's walls, or floor etc.

Finally, ventilation heat loss. There is no method to calculate the air change rate. The common name of the measured or evaluation method, for ventilation heat loss, is air tightness testing. There're various methods for this, in BRS we prefer the low-pressure pulse version, because you can do room by room tests for more accurate data. As we all know, draughtproofing is the method to reduce ventilation heat loss. and we'll move on to this very soon, but just to say here, that over draughtproofing can lead to serious problems.

Thermal energy balance: heat loss & heat gains

The important thing to remember about the three heat loss pathways, is that changing one will affect the others.

For example, if you improve the planar U-value of the ceiling, but not the wall, this will increase (or make worse) the psi value – which is the rate of heat loss through the junction between the wall and ceiling.

Improving all heat loss pathways, together, at the same time is the only logical way to move forward.

Importantly, when addressing the heat losses, you need to be conscious of the heat gains.

For gains, you have three main categories:

1. **Metabolic heat gains:** including evaporation from people and other living animals (warm-blooded pets)
2. **Solar heat gains:** from the sun, through the windows
3. **Equipment heat gains**: including cooking, lighting, fans + pumps and latent gains from water heating. Directly or indirectly from appliances other than the heating systems (direct = oven)(indirect fridge and freezer)

Thermal energy balance: heat gains account for as:

So, let's apply this knowledge to a retrofit example. And I want to demonstrate the balancing between heat losses and heat gains. So here I'll use the u-value for heat loss, and solar for heat gains.

On this slide, I have the heat gain profiles for the same tenement flat. This is a retrofit assessment, between 2 different window retrofit options. All of this comes from actual measured, monitored and calculated data that we - BRS - have acquired over the years.

The pie chart on the left shows the heat gains profile and total space heating demand for the flat, if it were to have all the windows retrofitted with secondary glazing.

The pie chart on the right, is the heat gains profile for the exact same flat, but if the windows were to be replaced by a triple glazed system.

Both the secondary and triple glazed systems had the same u-value – 1.7W//m2K, which is crazy low by the way. Which is good.

The difference is, the Total solar energy transmittance, or g⊥ value (which is a measure of how much solar heat energy passes through the glazing. And is used for calculating solar gains.)

Whilst both have the same U-value for heat loss, the secondary glazing system had a GT value of 0.76 whilst the triple glazed alternative had a GT value of 0.57. This GT value is a ratio 0-1, the higher the value the more solar heat energy you get from the sun. for context, a single sheet of glass, at 3-4mm thickness will have a GT value of 0.9.

The text above each chart shows the effects of the retrofit systems on the flat's total heat gains, and its ultimate effect on the flat's total space heating demand for the year.

So, the **Message here is**, the selection of retrofit measures demand special care and consideration, especially windows. Retrofit specification should never been seen as 'looking up the Argos catalogue' for the cheapest material or system. And, when you're speaking with your designer or retrofit installer professional, always bear in mind that the U-value should not be the only metric by which you evaluate the retrofit option, especially for your windows.

So a good (low) u-value will reduce the heat losses, but you may not want to sacrifice solar heat gains to achieve that lower u-value.

Thermal energy balance: thermal comfort (1)

Now. I know what all of you are thinking. … you're thinking 'solar gains vs window U-value' that's only a part of the picture. And you're right. So that begs the question, what about over-heating?

There was a simple calculation method that considered the building's heat losses and gains over 3 summer months, to predict the risk of internal temperatures going over the external temperature threshold. Much of that has been replaced with complex and expensive dynamic simulation modelling.

But what does that mean for retrofit?

Well, we should focus on the term thermal comfort as opposed to overheating. And you are well within your right to ask your retrofit construction professional for an overheating risk assessment and thermal comfort assessment. Which will include an assessment of the dwelling's surface temperatures.

And this is where thermal mass comes in.

For existing buildings, especially those constructed with mass masonry, they often get a bad rep for being 'hard to heat', a better term is probably 'hard to keep warm'.

Thermal energy balance: thermal comfort (2)

If you have a building with high levels of thermal mass, that means it was constructed using mass masonry – like stone or concrete or blocks, those materials can act like a thermal sink.. Which means the core of those elements – like a solid stone wall, can absorb large amounts of heat from the ambient air around them. Which, in turn, creates lower surfaces temperatures for that wall until the whole wall reaches the same temp as the ambient air around it.

This means, when you sit close to a mass masonry wall (specifically internal walls) that has a low surface temp, that heat sink will absorb metabolic heat (from your body) faster than most of the other objects in the room, like fabrics and furnishing. This often translates into "feeling cold" near that surface.

That accelerated heat transfer, between your skin and the cold surface, happens at such a rate that most people mistake that radiant thermal exchange as convective thermal exchange.

Lower surface temperatures are very easily mistaken for being a draught.

Then what happens … out comes the draught proofing foam and tapes etc. (**which is very dangerous, we'll take about that soon).**

I have a few metrics on screen there, which are used as key performance indicators of how the internal thermal comfort levels can be measured before and after retrofit.

Also, after retrofit, or 'post retrofit', be prepared to alter the heating schedule, timer, set point temp etc. on the space heating system to help the surface temperatures and ambient air temp get into better alignment. This often translates into, heating the home for longer at a lower temperature post retrofit.

Thermal energy balance: over and underheating

Ok, that's overheating and the importance of thermal comfort. But what about under heating?

I have to say, as building physicists we've always been deeply concerned about the detrimental impacts that fuel poverty has on a building's wellbeing, and the catastrophic and eventually fatal effect that fuel poverty has on the occupants.

But I want to talk about unconscious underheating.

This comes down to building physics vs its cousin building economics.

I'm not an economist, but I do pay the utility bills, and that is the only qualification you need to understand this next bit.

Let's look at a mid-floor tenement flat, in Edinburgh's New Town.

Let's say it has a space heating demand of 15,000 kWh/year

So, that dwelling needs 15,000 kwh/year to

a. Achieve the occupant's thermal comfort,

b. Keep the dwelling's envelope healthy, i.e. keep the Relative Humidity (RH) of the air down, and surface temperature up,

Lets say that this flat is gas heated. And let's select 5p/kWh as the tariff. To generate that 15000 kwh/year, you paid £750 a year

Now, if you're using £ as your benchmark for building performance and are locked into trying to keep the space heating demand to a certain £/year, then, as heat fuel tariff prices increase, the risk of unconscious underheating is significant.

Let's say, we've paid around £750/year to heat our home, then the tariff jumps, from 5p to 10p/kwh (for simple math), but you're adamant that the house only needs £750/year of heat to maintain a healthy and comfortable home. This results in underheating.

If your fixated spending only £750/year, and the tariff doubles, then the amount of space heating that you're delivering to the home is effectively halved. This results in 3 things.

1. first, and the most instantaneous and obvious, you're colder for longer.
2. Next, levels of RH take longer to drop, because the air temp is lower
3. Not long after that, the surface temps are lower for longer. As we just talked about, the knee-jerk reaction to feeling colder surfaces, because you think that that 'feeling cold' sensation is ventilation heat loss, is draught proofing. It very well might be ventilation heat loss, but it's not guaranteed, especially if you've 'just started to feel cold in those parts of the home. So, what happens next,? More draughtproofing. We've monitored far too many people blocking off and closing mechanical extract fans, because when you've already maxed out the draught proofing, you can get obsessed with finding that draught, when there might not be one. So what happens next? Co2 levels and PM2.5 level start to rise, and they'll continue to rise towards levels that are hazardous for health … then what happens? … headaches, migraines, changes in mood, drops in cognitive ability, skin and respiratory health issues.

The message here, is two fold:

1. Don't use £/month or year as an indication of how much space heating energy your building needs.
2. whilst we are all at the mercies of the energy gods, in relation to tariff prices, we need to compensate our understanding of our indoor environments. This mean looking beyond air temps as the sole metric to define the comfort of our homes.

What does this mean? - until tariff prices come back to some form of normality and market competitiveness takes away some of the burden – we must consider technology like dehumidifiers and air purifiers if we are forced to underheat our homes.

These 2 technologies are becoming essential to help the lower ambient air temperatures, from our heating systems, to control levels of rh and levels pm 2.5.

That means, you can use your extra blankets and warm clothing layers to help with your thermal comfort. And you can use dehumidifiers and air purifiers to help manage levels of RH and indoor air pollutants, for good indoor air quality.

Now, just a sense check warning, the only thing that will remove levels of CO2 from your indoor environment is active ventilation, whether that be wind driven natural vents or continuous mechanical vents. it may be necessary to de-retrofit some of the draught proofing to get those levels of air change rates back up to comfortable and healthy levels.

But, how do we know if we need a dehumidifier or an air purifier, or more or different ventilation system?

Well, that brings me nicely to the next section of this talk ….

What I'll be covering: Water transfer and Ventilation

Water transfer and ventilation.

Water vapour balance

Let's start with a few scientific facts:

1. Water exists in 2 of its three forms in our homes and in the materials that we've used to build our homes. These are liquid water (often called moisture) and water vapour (also often called moisture).
2. Every porous material, in your home, i.e. timber, brick, plasterboard, lath and plaster, stone, will have some level of liquid water residing in its cells or pores. This is called a material's moisture content, and it will vary, sometimes on an hourly basis. Sometimes monthly. But it will vary, whether we like it or not.
3. Water vapour is often assumed to be only steam, like from boiling water, only moving during times of high energy exchanges like when a shower is on. So that's only partly correct. The water vapour that I want to refer to, is both the high energy steam, but also the low energy water molecules that are always all around us. These low energy varieties transfer due to differences in pressure across your buildings internal and external surfaces.
4. The pressure difference, on either side of your wall, for example, partly dictates the transfer of water vapour through your building's thermal envelope. Just like temperature dictates the transfer and balancing of heat across your building's envelope, saturated and partial vapour pressures dictate the transfer and balancing of water vapour.
5. The last scientific fact worth mentioning is that water vapour transfer observes the same principles as electricity and heat: it will follow the line of least resistance. So, water vapour pressure differential, which is measured in kilopascals, does not naturally want to transfer through various densities of materials that make up your wall, for example. The water vapour levels internally do

want to balance with levels of water vapour externally, but it will prefer to do that via the line of least resistance, i.e. via the building's ventilation system or strategy. Which, for most of us, means – our buildings trickle vents, and our intermittent mechanical extract fans, and we open doors and windows when necessary – that system, that natural or passive ventilation system, is the primary means for water vapour internally to balance with the levels externally.

Now, what happens if we start to draught proof … we lower ventilation heat loss, which is a good thing. Right? Well not necessarily. What happens if we draught proof some more … then more again, then start tampering with the extract vents … then we start draught proofing internal doors, etc. …… now, that water vapour has only one route to balance with the external, and that is through our building's thermal envelope. and that is not a route that you want the internal water vapour to take.

This brings me…

Water vapour and ventilation

…on to the phase change of water. Specifically, vapour to liquid.

So, water vapour doesn't want to undergo the kilopascal pressures changes to get through a bunch of materials, but it will if it has to – if, for example, the ventilation system has failed, or over-retrofitting draughtproofing has compromised that system's ability to balance levels of internal and external water vapour in the air, then water vapour will push through the walls, ceiling, junctions and joints etc. in order to balance or harmonise with the external.

But, the important thing to note here, is that levels of water vapour will travel at a different rates compared to heat, through the materials in your wall, for example.

So, if at any point in the heat's and water vapour's journey, through your wall for example, from the inside to the outside, if the rate of those two differs significantly (by significantly, I mean the rate of heat transfer is faster than the rate of water vapour transfer), then the water vapour will condense into liquid water.

If that happens at the very first layer of the thermal envelope, i.e. the lath and plaster surface of the wall, that is what we call surface condensation.

If that happens somewhere between the walls internal and external surface, that is what we term interstitial condensation.

Now, what does all of that mean? For retrofit materials you often hear the word 'breathable'. Meaning that a so-called breathable material can handle the water transfer (from vapour to liquid, i.e. condensation) in a wall for example.

Firstly, your wall or ceiling or whatever, should never be expected to handle large amounts of condensation.

Secondly, breathable is not a scientific term and it cannot be measured.

Breathability is actually a combination of 3 water transfer parameters:

1. Hygroscopicity
2. Cell structure
3. Permeability

Lastly, be very careful of any construction professional that immediately disregards a certain material or retrofit position of a material without understanding the hyrgothermal dynamics and ventilation strategy of your particular home as this can influence the success of any retrofit material.

A perfect example of this is phenolic foam insulation on the inside of solid stone walls. Or polyurethane or polystyrene insulation behind the lath and plaster, filling the air layer.

I've monitored walls like that which have worked fine, and others which have been a total disaster.

But why? Why do some materials work fine in some dwellings, but not in others. In most instances it comes down to the levels of moisture content in the pre-retrofit wall, and aggressive draughtproofing, with no consideration for ventilation systems.

The message I want you to leave with here is, there are two types of ventilation, and both combine to make up the total amount of ventilation heat loss.

1. The first is what we, in the industry, call unregulated ventilation. That is the closest thing to what most people call a draught. These are air movement pathways that you can't regulate (via a switch or a lever so you can never close them or turn them off). These are draughts around poorly fitted windows, poorly sealed chimneys, pipes and ducts that penetrate through the thermal envelope.
2. The 2nd type of ventilation is called regulated. This means the amount of air, that travels from the internal to the external, through the building's actual ventilation system. If you are in a tenement flat in the Edinburgh New Town, your ventilation system is going to be something like intermittent extract fans in the wet rooms, and times when you open your external doors and windows.

There will always be a necessary heat loss penalty to properly ventilate your home. But the unregulated heat loss paths, around dodgy windows, and pipes etc. are not and should not be considered as part of the building's ventilation system for maintaining good indoor air quality.

The take away message here is: **never rush to retrofit,** no matter how tempting or under pressure you are to change the thermal envelope. Stop, think, and listen to the building.

It is essential to make sure that your building is actually **ready to retrofit**, before doing anything.

And a trusted, experienced construction professional, seasoned in the science of retrofit and building performance evaluation, will take you through these steps.

Please don't trust a construction professional that says something like "yeah, we don't need to do any pre retrofit measurements, we've worked on/or installed on this building type for years". My response to that is, 'sure, but have you worked on this exact house or flat. Do you exactly know the moisture content of the stone on the north east facing wall, or the ventilation pathways of this exact dwelling?' because, if that answer is no, then they do need to do pre-retrofit measurements for baselining.

But what can you do to inform your decision, and to give you the power for thermal retrofit projects?

Well, as with almost everything, knowledge is power..

<u>What I'll be covering: data capture</u>

And that knowledge comes from data.

So now I want to talk about the types of data that you can get, and your construction professional can get, to better inform any decision.

And I'll cover the cheap and cheerful hardware that you can use, along with the scientifically calibrated stuff that you should expect your industry professional to come in with.

<u>Decision support tools: data and hardware (1)</u>

The terms we'll be using here are pre and post retrofit, meaning before and after any thermally insulating material is added.

We use the term measure to capture single point in time values, like an IR camera or moisture content meter, and we use the term monitor to capture values over time, like internal comfort conditions.

So why measure? Why go through the rigmarole of getting data?

First, the pre- data gives you and your construction professional a baseline for the hygrothermal and ventilation performance of your building. This acts a benchmark, that the professional can then use to calibrate digital models of your building, which is used to short-list the selection of retrofit measures, and greatly assist with the specification of the optimal retrofit solution.

Now this we call 'de-risking' the retrofit process.

Secondly, the post retrofit data gives you values to compare to the baseline, or pre-retrofit values. This will let you quantify the impacts of the money you spent, but also these datasets provide you with the vital 'canary in the mineshaft' insights. It lets you see, as early as reasonably practicable, if something untoward is happening. After retrofit, it will take a while for the sub-environments, within your home, to adjust to the changes to the building's thermal envelope. So, if something bad is happening, you want to detect that as early as possible.

Decision support tools: data and hardware (2)

So, how do we measure?

Lots of hardware is the answer. Some of that hardware is cheap and cheerful and super intuitive, and some items are very expensive, require specific training and deeper knowledge of building physics and the apparatus.

I really wanted to go through process and cost of equipment here but in the interests of time have omitted much of what I was going to say on this slide section. Simply put, there is low-cost equipment, and free to access to citizen scientists' websites, like those on the left of that screen that allow you to monitor the home yourself. (e.g. Inkbird and Huma-I monitors and Weather Underground – wunderground.com). Paired with weather-adjusted energy billing data and spreadsheets you can get a good baseline pre-retrofit, and understand the impacts after.

Whereas your construction professional can provide even more intel using more expensive equipment, which I have shown on the right of this page.

Take home message

So, the take home messages here are:

Again, don't **rush to retrofit**. Get the data, create a baseline, satisfy yourself that you are investing in the right retrofit measures.

Make sure that the building is **ready to retrofit**. This could mean, removing some of the earlier retrofit work or repairing and restoring something before more, new material is added. Carry out maintenance and repairs.

Don't be afraid of the data, and find a construction professional, with retrofit experience, and building physics knowledge, to talk you through what the data means. Which brings me nicely to final section of our talk this evening, which is…

What I'll be covering: Whole building EE retrofit

Whole house or whole building Energy Efficiency retrofit.

Here, I want to briefly set out the locations of, and types of, thermal retrofit measures that we can add to our existing buildings. And, importantly, the things that you should be aware off.

This isn't an exhaustive list, neither is it a list of specific products or brand. Also, I'm not one of those construction professionals that likes to make the retrofit process 'measure centric',

Meaning, choosing the specific retrofit material before understanding the building.

I, like the best of us out there, like to start with – what we call - an 'archetype centric approach'.

Which means, we get data from the building, which will tell us what material is best, and the optimal location to install that material.

But, because I don't have a specific building here, I'm going to keep my comments here a little more generic than I'd otherwise like.

Retrofit measures : mindfulness (1)

Let’s start, as many of us do, with Draught proofing.

So, things to be aware of. Pre-retrofit, do you currently experience overheating in the summer? If so, post retrofit, those levels could get worse.

What are the pre-retrofit **air change rates**? Are they just above adequate? If so, post retrofit, those levels are very likely to drop and get worse. That means that the post retrofit air change rate could compromise other retrofit measures e.g. Internal Wall Insulation (IWI) and secondary glazing.

So, you want to see results from a pre and post retrofit air permeability test. To see 2 things, 1 that the ventilation heat loss has reduced, and 2, air change rates haven’t reduced to hazardous levels, for either you or the building.

Ventilation system

Passive (natural) ventilation is wind pressure driven, and it might not be sufficient to deliver adequate air change rates post retrofit. Which mean the building is in danger of being over retrofitted. The solution here is either, de-retrofit, to increase those unregulated ventilation pathways – which is now always advisable. Or change the ventilation system to a continuous mechanical ventilation system, that you can control and regulate..

Walls – we have **3 insulation types** or – think of them as locations

IWI – things to be aware of:

- The ventilation strategy for the house: Is it adequate pre-retrofit? And, Would too much draught proofing – post retrofit - reduce air change rates to a point where water vapour is forced to transfer through the insulation? If so, you may be looking at surface or interstitial condensation.

Cavity Wall Insulation (CWI)

- Is the cavity actually ‘ventilated’ i.e. air in the cavity to connected to the external environment. If so - and that air movement is serving a particular purpose - then filling that cavity might be a bad idea.

External Wall Insulation (EWI)

- Continuity of the thermal envelope is vitally important, which is why EWI is so common for certain archetypes ….. For EWI it is essential that the installer removes **everything** from the external surface …. Alarm systems, downpipes, lights etc… *EVERYTHING*!

For all insulation types:

Make sure that the designer and by extension, the contractor, addresses those thermal bridges. The junctions around corners and edges.

You want to see IR thermal images, pre and post, and you want to get fRsi temperature factors values for those bridging locations. Remember that temperature factor values are a critical assessment for the risk of surface condensation.

Retrofit measures : mindfulness (2)

Doors

Solid doors. Things to be aware of.

- When insulation is added to the inside surface, things like letter boxes, hinges, locks and the ‘swing’ of the door can be compromised.
- For doors that are wholly or partially glazed – makes sure that window gets considered.
- Treating the door’s vision panel or light well with secondary glazing typically helps here.

Windows

Things to be aware of

All types: If you can and want to replace the window, then be aware of the relationship between heat losses (the U-value) and heat gains (that GT value I spoke about earlier).

If the window is worth keeping, or keeping it is non-negotiable …

- Repair and restore as much of the original window frame, and mechanisms as possible.

For Glazing – things to be aware of:

- Decide if you want to improve just the glazing (glass panes) i.e. low-e film, thin double or 'stick on' polycarbonate for double glazing, or if you want to treat the whole opening i.e. secondary glazing.
- For any system, be aware that you'll need to clean and maintain those windows.
  Treating the whole window (i.e.) secondary glazing, will improve the u-value for the entire opening, including the glass, the frame, and reduce unwanted, unregulated ventilation heat loss. Where a pane-only solution will not.

Retrofit measures : mindfulness (3)

Roof

Things to be aware of:

Ceiling:

- You want insulation laid above and between the ceiling joists. Watch for compression with any attic flooring systems. Inspect the ceiling insulation after any work has been done in the attic, e.g. electrical, plumbing, TV etc.

Coomb (section of sloping ceiling):

- Do not allow the ventilation pathway, from the eaves, which is where the roof gutter is, into the attic to become blocked or filled full.

Rafter:

- Be aware of any water vapour resistant material, like the old bitumen felt, that might be under the slates or tiles.

Floor

Things to be aware of:

Any floor:

- Be aware of the composition. It is common for pre-1970s building to have a timber suspended floor in some parts, then a flag stone or concrete floor in the wet rooms i.e. bathroom, kitchen etc.

Solid floor:

- Be aware of the changes in height, (floor to ceiling)

Suspended floor:

- Insulation between joists tends to be the only solution here.

Post retrofit evaluation. What to look for

So, Post retrofit evaluation. What to look for?

- Well, when you get the post retrofit data, and you are comparing it to the pre retrofit data, increases in anything is typically bad, i.e. increases in:

- Summer ambient internal temperatures
- Internal RH, above 70% for prolonged periods
- Internal CO2, for prolonged periods
- Internal pm2.5 levels, for prolonged periods
- Winter space heating fuel … energy bills

But make sure that your data is weather normalised to allow for comparison between the years.

Final message

- Flatted dwellings can be more challenging. Specifically, because your dwelling's thermal envelope will most likely include a wall and or floor or ceiling etc. that is part of your neighbour's thermal envelope. So, when you're adding insulation to your thermal envelope, you want a whole building solution, which includes those junctions and joints, aka the thermal bridging points that we spoke about earlier. So that is typically the time to involve the Edinburgh Building Retrofit and Improvement Collective in these discussions.
- Be aware of any construction professional that resists pre and post retrofit monitoring. And construction professionals saying 'we don't need to measure anything. We know all about sandstone walls'. They might know the theoretical performance of sandstone walls for example, but they need to know the specific hygrothermal performance and ventilation pathways of your home before anyone starts adding any insulation materials.
- You might be told that it'll cost you more money and time to do a proper retrofit building performance evaluation. It doesn't cost that much in terms of money, but it will cost time. As some of those measurements and monitoring can only be done over a winter period and/or a summer period, it will cost time. But, ultimately, can you really afford to get the retrofit wrong, especially with so many low cost monitoring options out there?
- Finally, we've not touched on wider environmental impacts at all, but just to give the last word to holistic sustainable retrofit: If your personal priorities also include the environmental impacts and whole life cycle sustainability credentials of a material's embodied carbon, again you are well within your rights to ask your chosen retrofit professional for an EPD – Environmental Product Declaration. These EPDs aren't new, and a professional can talk you through what the numbers mean.

Thank you

So, I want to leave it there. Thanks to all for listening. I hope that that was valuable and you've picked up some useful tips.