webinar
2025.09.18

Overview and Context

Indoor Mould Risks growing health concern

Indoor mould growth poses increasing health risks due to elevated humidity and moisture in buildings influenced by climate change.

Mould exposure and health Impacts

Mould exposure is linked to respiratory, cardiovascular, allergic, and cognitive health problems reducing quality of life (DALY's).

Webinar Focus

The webinar **will explore assessment methods, in-situ measurements, and predictive modelling for mould risk management.**

1

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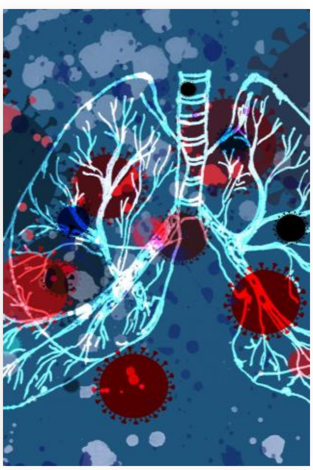
Indoor Mould Risks and Technological Priorities



Health Impacts of Indoor Mould

Exposure to indoor mould causes respiratory, cardiovascular illnesses, allergies, and cognitive decline impacting public health significantly.

Building Vulnerabilities

Most buildings lack moisture-resistant designs, leading to increased mould growth due to elevated humidity and climate change effects.

Technological Innovations

Development of predictive simulation tools and affordable diagnostic technologies are vital for detecting and mitigating indoor mould risks.

Standardized Measurement Protocols

Standardized protocols ensure reliable and consistent mould measurements across different environments for effective mitigation strategies.

2

How to improve our possibilities to assess, predict and control mould risks?

Webinar

Feber, M. (Maaike) le

18 September 2025

1

Introduction

Mould is a known problem, which will increase due to climate change

- No thresholds for indoor air
- Causes of mould are combinations of a.o. building features and behaviour
- Buildings subject to several transitions (energy, green building materials, climate change)
- Multidisciplinary approach required

Maaike.lefeber@tno.nl

In this presentation:

1. How indoor mould is harmful to humans
2. Why health-based thresholds are lacking
3. TNO's (re)search for accurate and affordable assessment methods
4. Why modelling to predict and control mould risks is necessary

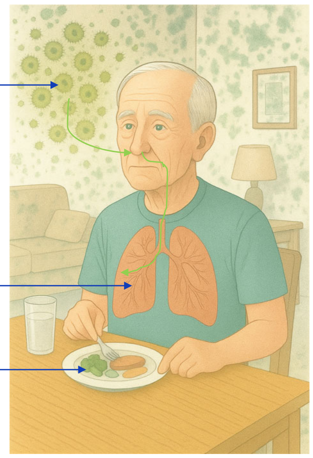
2

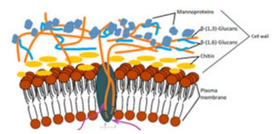
1. How indoor mould is harmful to humans

Prolonged inhalation exposure to **β-glucans** may cause chronic diseases like asthma an allergy (all moulds)

Some moulds can cause **infections**; some infections are live threatening

Inhalation exposure to **mycotoxins** not very likely in normal situations (some moulds)





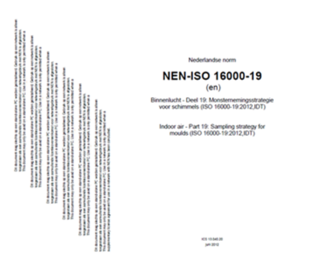
β-glucans are part of cell walls of living and dead spores and degeneration fragments

2. Why health-based thresholds are lacking

Standards for mould measurements are available, but…

- The sampling strategies aim to identify sources to prevent degeneration of the building structure; their aim is not to assess exposure to moulds;
- Some strategies only focus on visible moulds, while part of the moulds growing in buildings are invisible;
- Most measurements focus on living spores only and include a cultivation step;
- Currently no standardised measurement and analysis method to quantify occupant's exposure is available;
- Very small number of non-comparable exposure data → not possible to relate exposure to health effects → no threshold.

ISO 16000 series



CEN - EN 16868
Ambient air - Sampling and analysis of airbone pollen grains and fungal spores for networks related to allergy - Volumetric Hirst method

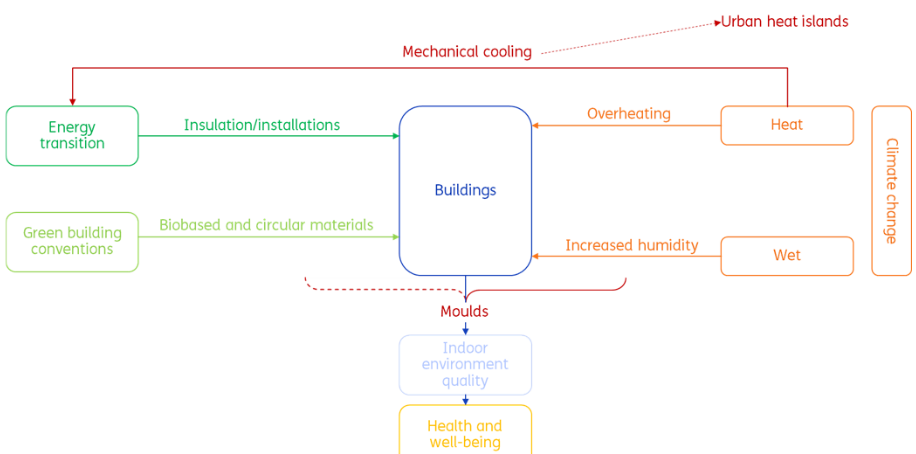
CEN/TC 137/WG 5 - MEASUREMENT OF BIOLOGICAL AGENTS (WORKPLACE)

3. TNO's (re)search for accurate and affordable methods

Existing methods are either health relevant or affordable, nothing in between

Method	Sampling	Analysis (quantitative/qualitative)	DIY/Lab	Mould parts	Costs	Health relevance
Visual inspection (of walls, ceiling, etc.)	-	Qualitative	DIY	Visible mould	low	limited
DIY agar plates	Deposition of dust from air on agar plate	Qualitative: visual, counts	DIY	Living spores	low	limited
IAQ sensorbox	Passive air sampling (RH, Temp, VOC, PM)	Qualitative: algorithm to assign mould index	DIY	n.a.	low	?
Settled dust samples (EDC, plates, wipes, tapes, swaps, vacuum cleaner)	Deposition of dust from air; extraction needed	Quantitative: ELISA, beta-glucan assay (e.g. Fungitell, Glucatell)	Lab	Cell fragments, living and dead spores	high	high
	Deposition of dust from air; (extraction and) cultivation needed	Identification/quantification: Maldi-tof, qPCR, DNA barcoding	Lab	Living spores	high	high
Air samples	Active sampling with filter, impinger or impaction on agar plates; extraction and/or cultivation needed	Identification/quantification: ELISA, beta-glucan assay, Maldi-tof, qPCR, DNA-barcoding	Lab	Cell fragments, living and dead spores in air	high	high

4. Why modelling to predict and control mould risks is necessary



Thank you

Looking for collaboration on measuring and modelling of health risks due to indoor mould growth?

Please contact us!

Maaike.lefeber@tno.nl

TNO innovation for life

How to improve our possibilities to establish, predict and control mould risks?

Webinar

Feber, M. (Maaike) le

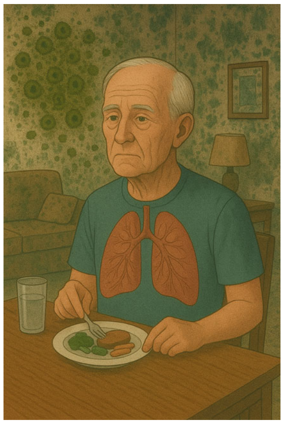
18 September 2025

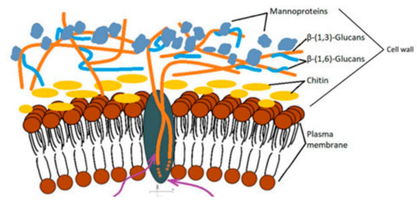
Theme name Place text here

1. How indoor mould is harmful to humans

Prolonged exposure to β-glucans may cause chronic diseases like asthma and allergy

- β-glucans in cell walls of living and dead spores and mould degeneration fragments of all moulds





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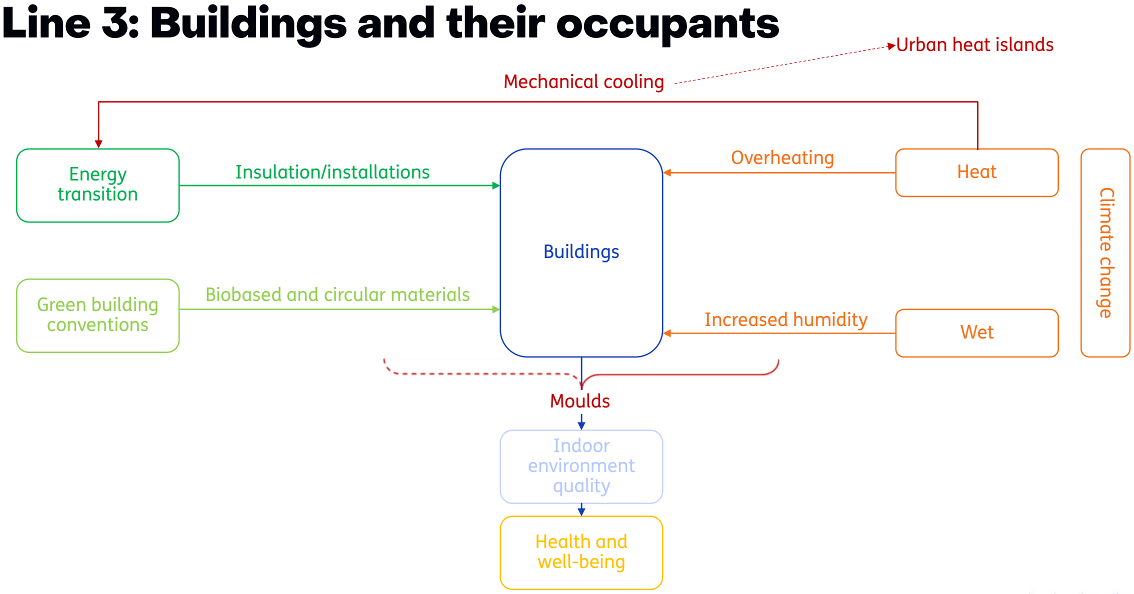
Line 3: Buildings and their occupants



Simulation-Based Prediction of Mould Growth Using Coupled Building and Fungal Models

Klaas De Jonge, Luca Maton

AIVC webinar - Emerging Risks of Indoor Mould: Assessment Methods, In-Situ Measurements & Predictive Modelling

18/09/2025

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GHENT UNIVERSITY

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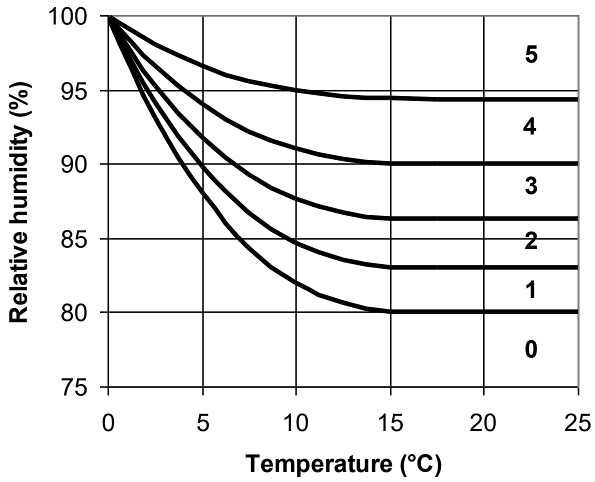
Mold growth conditions Pine [Hukka 1999]



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VTT

Finish mold growth model

Sensitivity class		Description	Examples
very sensitive	1	untreated wood, which contains high amount of nutrients	Roughly sawn and dimensioned plank (pine, spruce and hardwood), planed pine, birch plywood, untreated porous wood fibre board, cardboard-surfaced gypsum board
sensitive	2	planed timber, materials and films with paper coating, wood-based boards	Planed pine, paper-based bitumized/treated products and films, wood-based glued boards, pine or spruce plywood, bitumized/treated porous fibre board
medium resistant	3	cement or plastic based materials, mineral wool	Mineral wools, plastic-based materials, autoclaved aerated concrete, expanded-clay lightweight concrete, carbonated old concrete, cement-based products, bricks, cement bonded fibreboard, fibreglass-surfaced gypsum board
resistant	4	glass and metal, products containing mould-preventive additive	Glass and metals, alcaline new concrete, products containing mould-preventing additives

Decline factor C_{mat}		Examples
Strong decline	1	
significant decline	0.5	sawn or rough planed pine and spruce, autoclaved aerated concrete
relatively low decline	0.25	planed pine and spruce, glued spruce board, concrete, paper-coated PUR
almost no decline	0.1	lightweight expanded clay aggregate concrete, polyester fibre insulation, EPS, glass wool

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https://research.tuni.fi/buildingphysics/finnish-mould-growth-model/

VTT

TAMPERE UNIVERSITY OF TECHNOLOGY

Mold Index

	M		Visual / Microscopic
Very heavy	6	Very heavy and tight growth, coverage around 100%	Visual
Plenty	5	Plenty of growth on surface, >50% coverage (visual)	Visual
Visual <50%	4	Visual findings of mold on surface, 10-50% coverage, or,>50% coverage of mold (microscope)	Visual, Microscopic
Visual <10%	3	Visual findings of mold on surface, <10% coverage, or,<50% coverage of mold (microscope)	Visual, Microscopic
Several	2	Several local mold growth colonies on surface (microscope)	Microscopic
Small amounts	1	Small amounts of mold on surface (microscope), initial stages of local growth	Microscopic
No growth	0	No growth, spores not activated	

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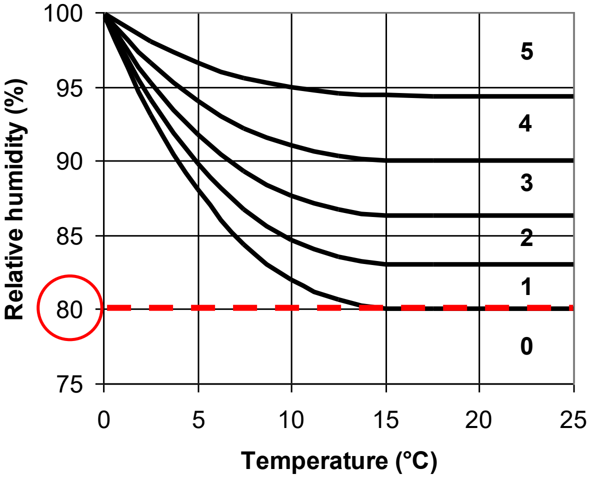
Mold growth conditions Pine [Hukka 1999]



Avoid mold growth: $p_i \leq 0.8 \cdot p_{sat}(\theta_{si})$

Vapor pressure indoor $p_i = p_e + \frac{R_v T_i}{\dot{V}} G_p$

$$\theta_{si} = \theta_e + f_{0,2}(\theta_i - \theta_e)$$

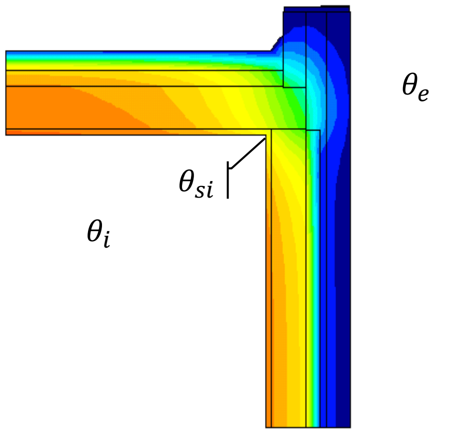
↑ Ventilation - $\dot{V}$

↑ Indoor temperature - θ_i

↑ Temperature factor (avoid thermal bridges) - $f_{0,2}$

Avoiding surface mold growth by design

$$f_{0.2} = \frac{\theta_{si} - \theta_e}{\theta_i - \theta_e} > 0{,}7$$



***for typical indoor conditions Belgium (up to Belgian internal climate class III)**

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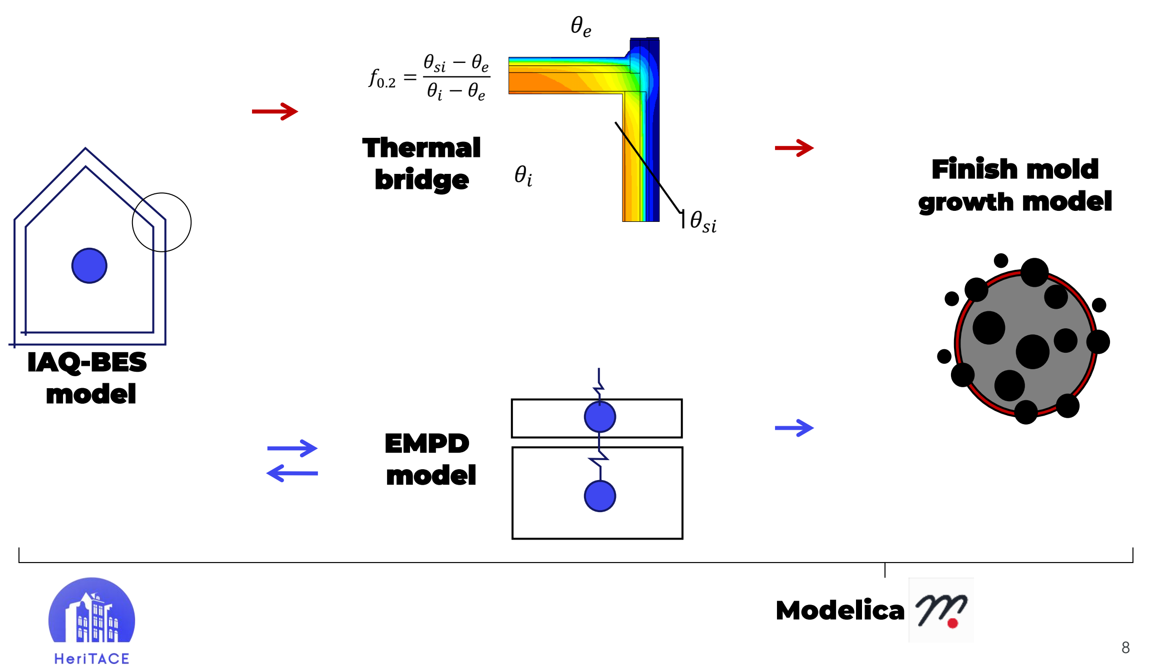

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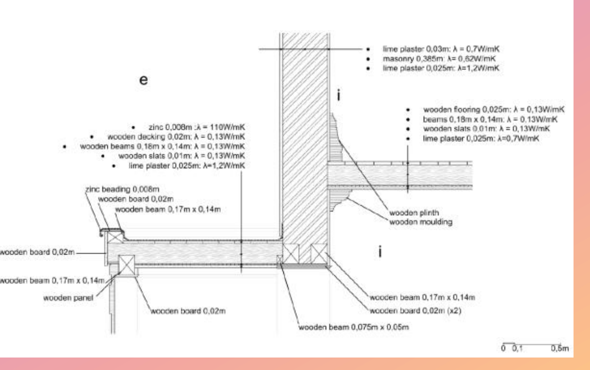
Application: Heritage bay-window



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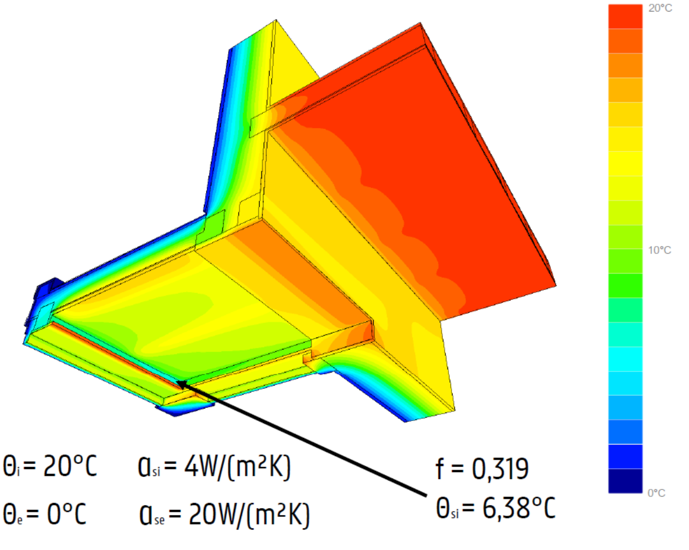
f = 0,319



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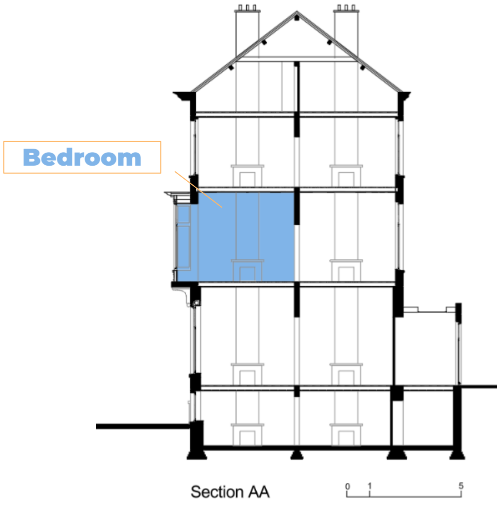
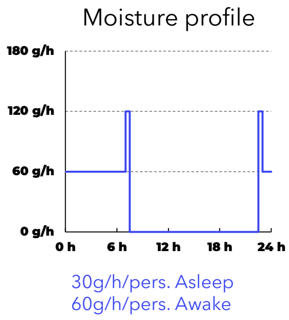
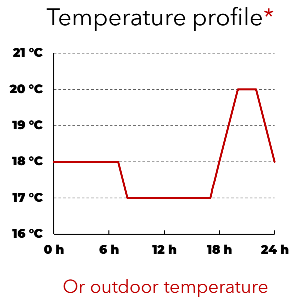
Author simulation - Baptiste Dewil

TRISCO







- No ventilation, leaky windows - ACH = 0,428 h^{-1}
- f = 0,319

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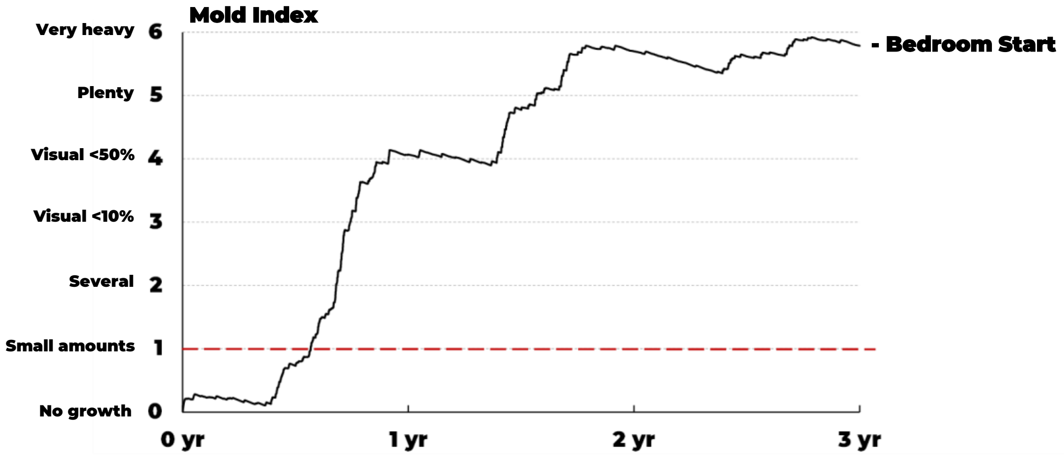

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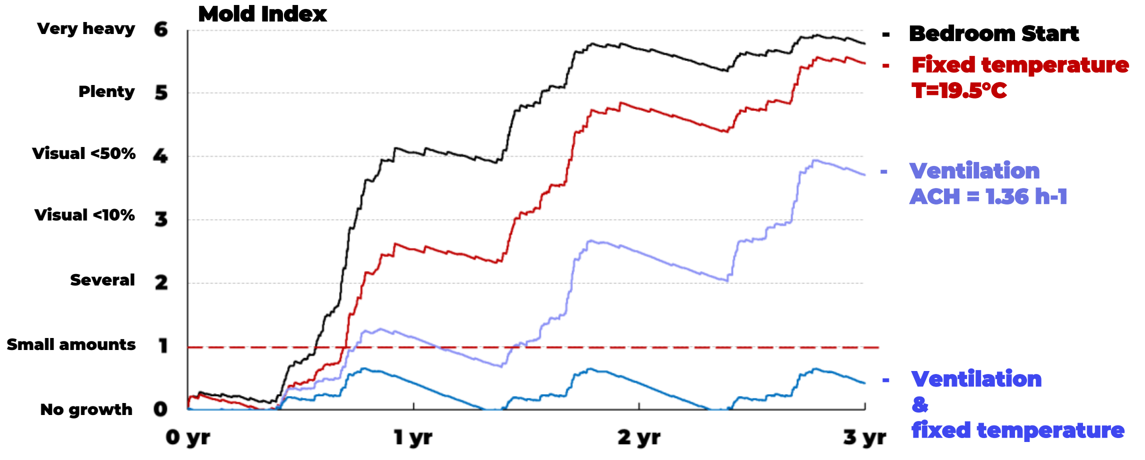
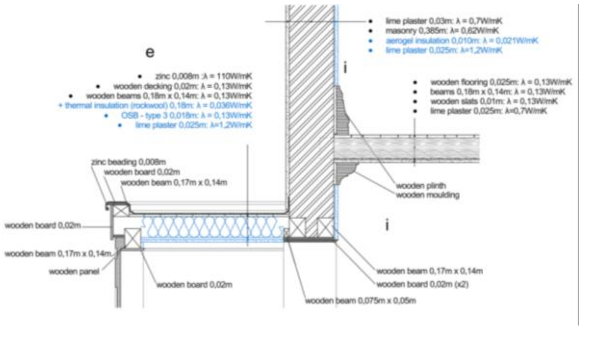
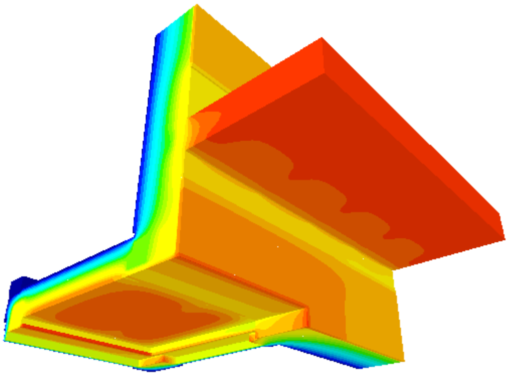


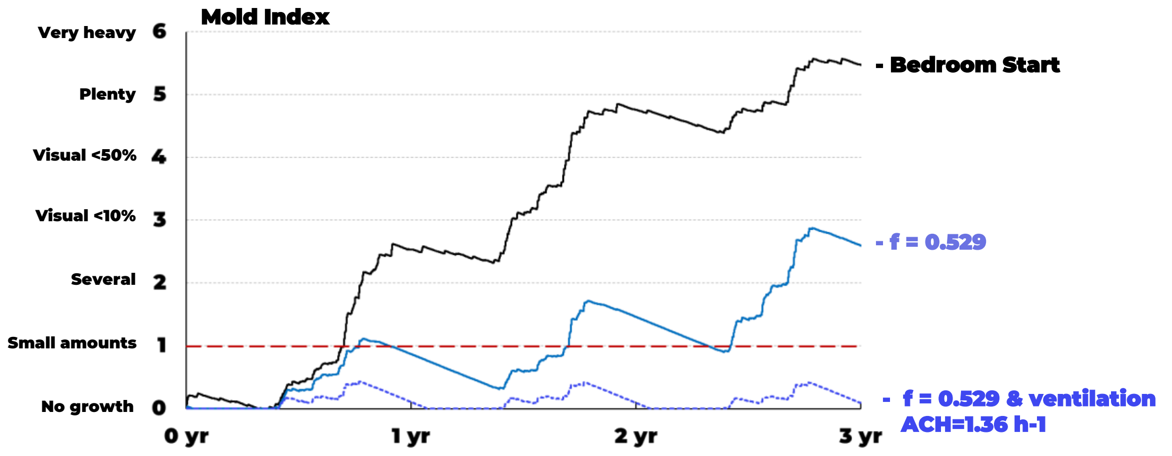
f = 0,529





Author construction detail and simulation - Baptiste Dewil

TRISCO



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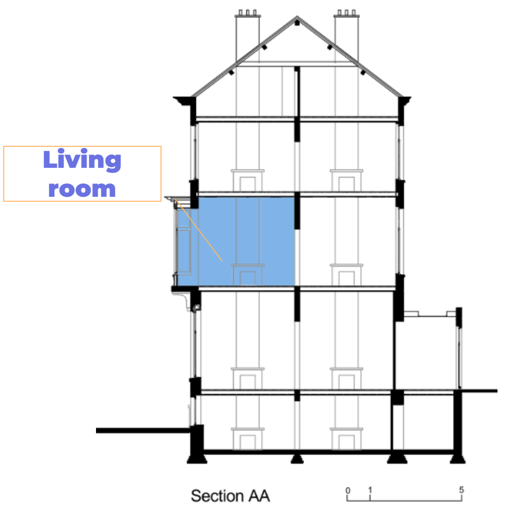

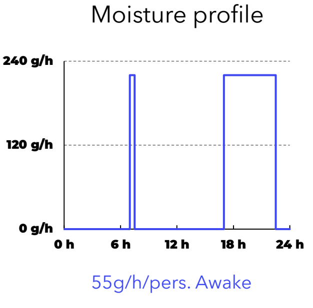

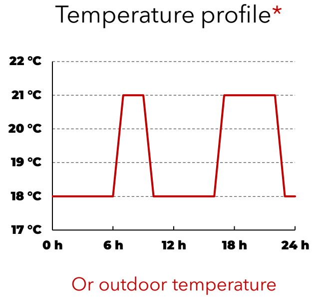

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- f = 0,319

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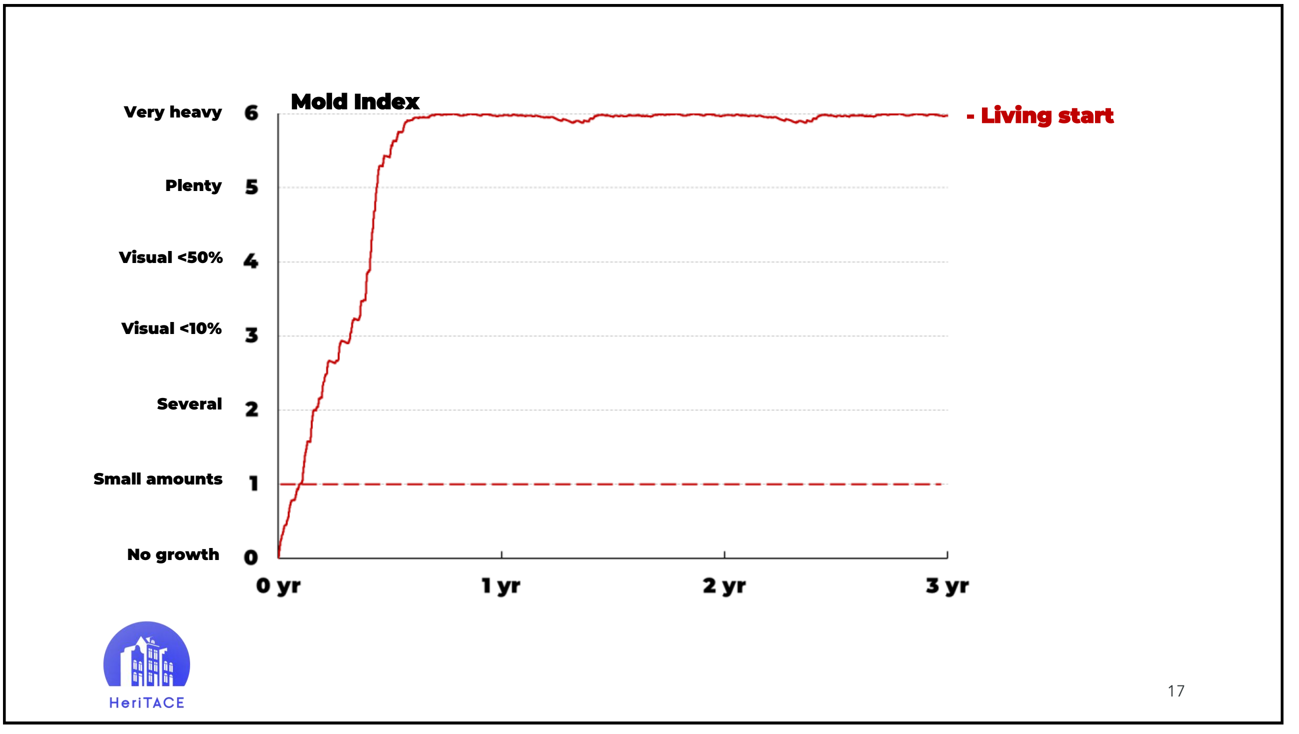
Mold Index
Very heavy 6
Plenty 5
Visual <50% 4
Visual <10% 3
Several 2
Small amounts 1
No growth 0
0 yr
1 yr
2 yr
3 yr
- Living start
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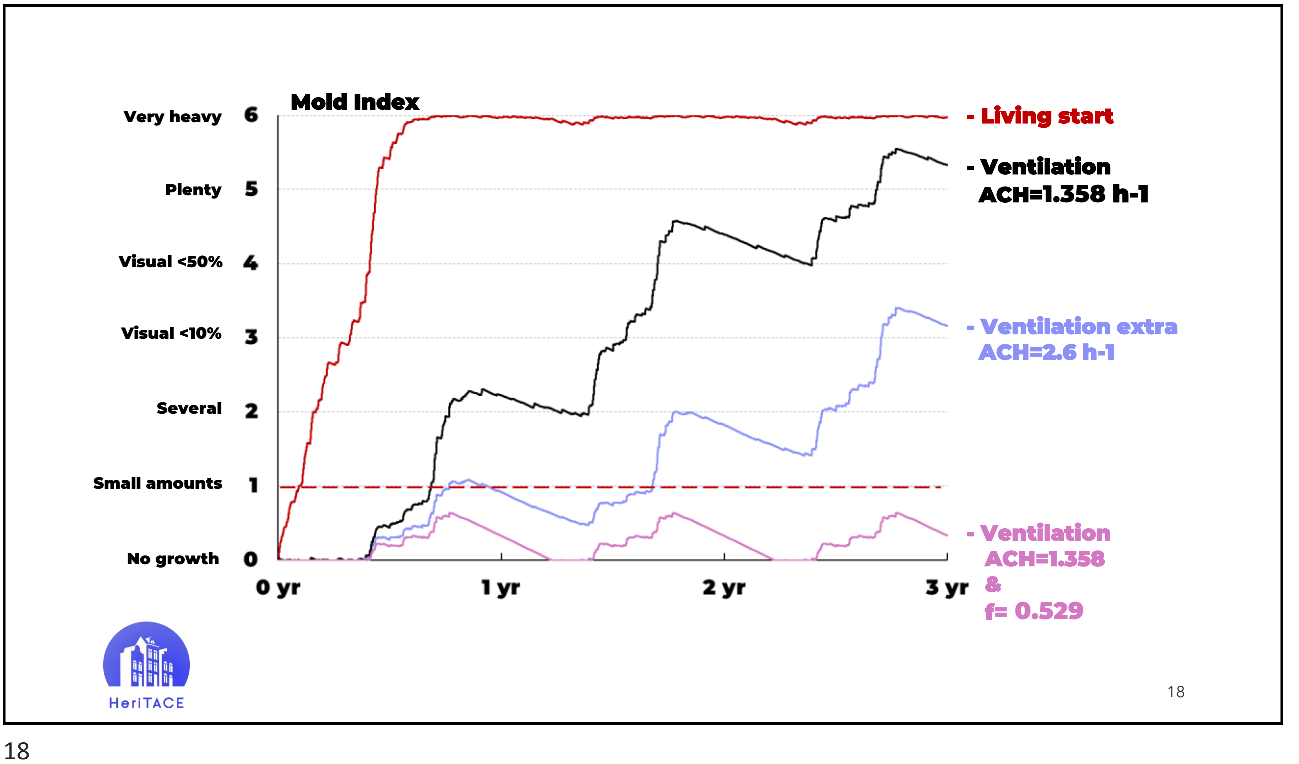
17


Mold Index
Very heavy 6
Plenty 5
Visual <50% 4
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Several 2
Small amounts 1
No growth 0
0 yr
1 yr
2 yr
3 yr
- Living start
- Ventilation
ACH=1.358 h-1
- Ventilation extra
ACH=2.6 h-1
- Ventilation
ACH=1.358
&
f= 0.529
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18

18

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University of Exeter

Modelling mould growth in domestic environments using relative humidity and temperature

Dr. Tamaryn Menneer

European Centre for Environment and Human Health

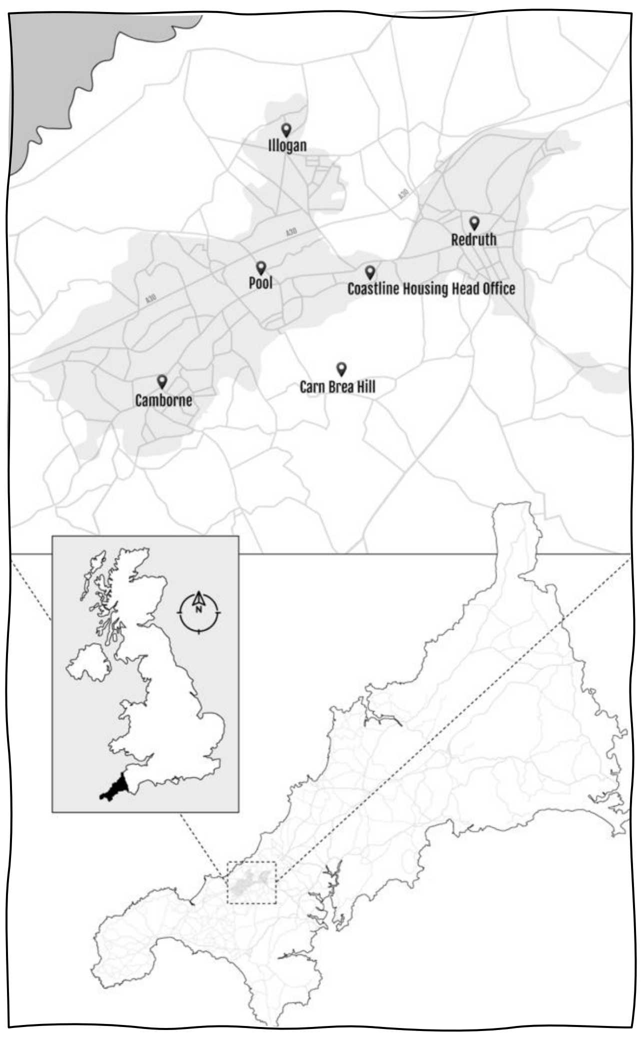
Environment and Sustainability Institute

1

Smartline

- 300+ participants from social housing
- Camborne, Pool, Illogan and Redruth, in Cornwall, UK
- Sensors and surveys

European Union European Regional Development Fund | HM Government | South West Academic Health Science Network | University of Exeter | Volunteer Cornwall | Coastline housing | Cornwall Council



2

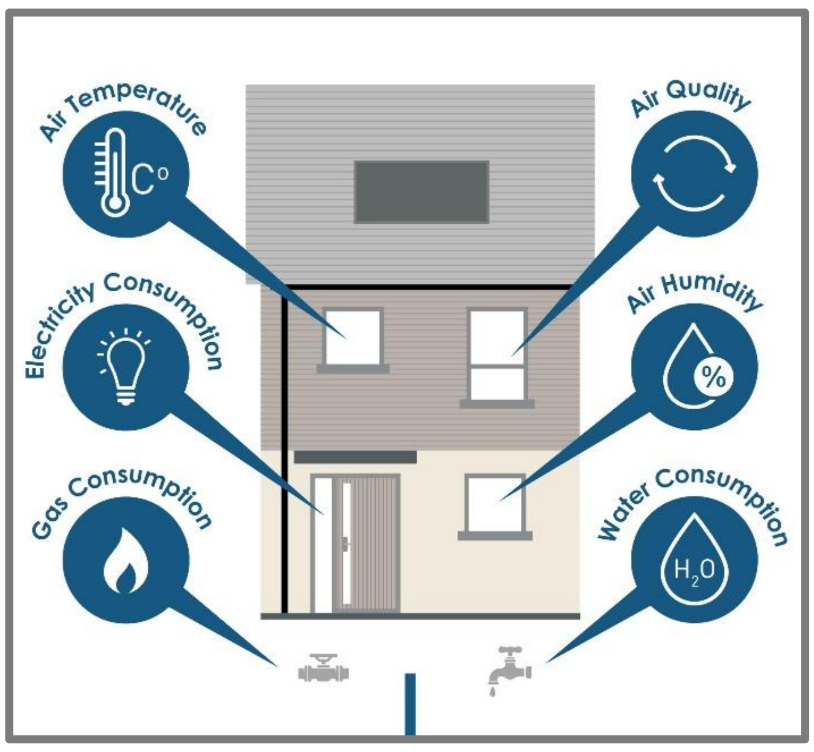
Survey data

- 95% white
- Two thirds female
- Average age 56
- Under-served areas
- One fifth no Internet
- 19.5 hours per day at home

University of Exeter

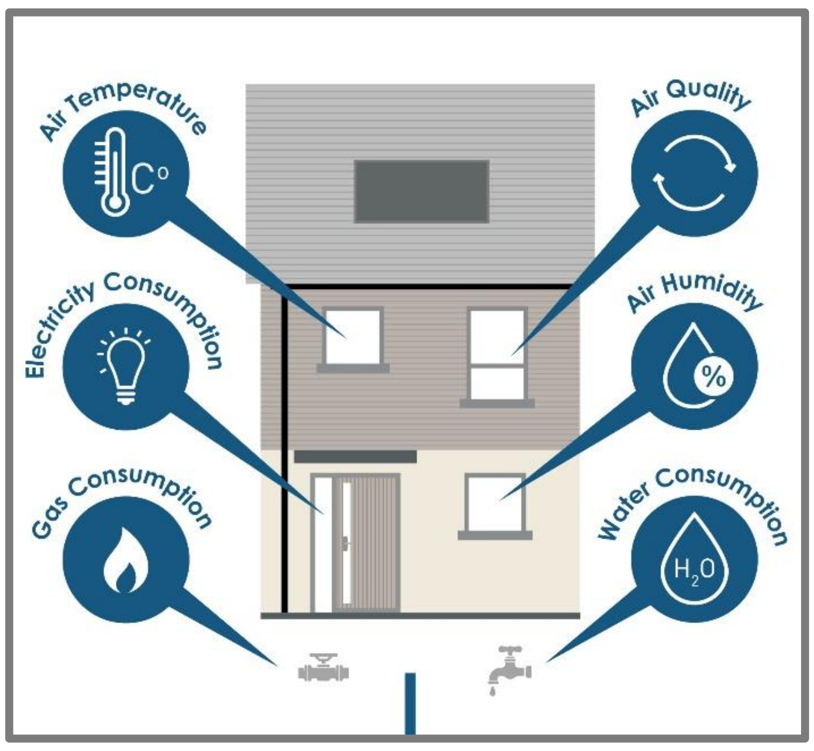
Sensor data

- Temperature
- Relative humidity
- Air quality
- External
- Utilities: Electricity, gas, water



Sensor data

- Temperature
- Relative humidity
- Air quality: VOCs, PM2.5
- External
- Utilities: Electricity, gas, water



Woods, Menneer, et al. (2023). Smartline Environmental Sensor Data and Utility Usage, 2017–2023. https://reshare.ukdataservice.ac.uk/856596/

Survey: Mould

Does your home have visible mould patches?

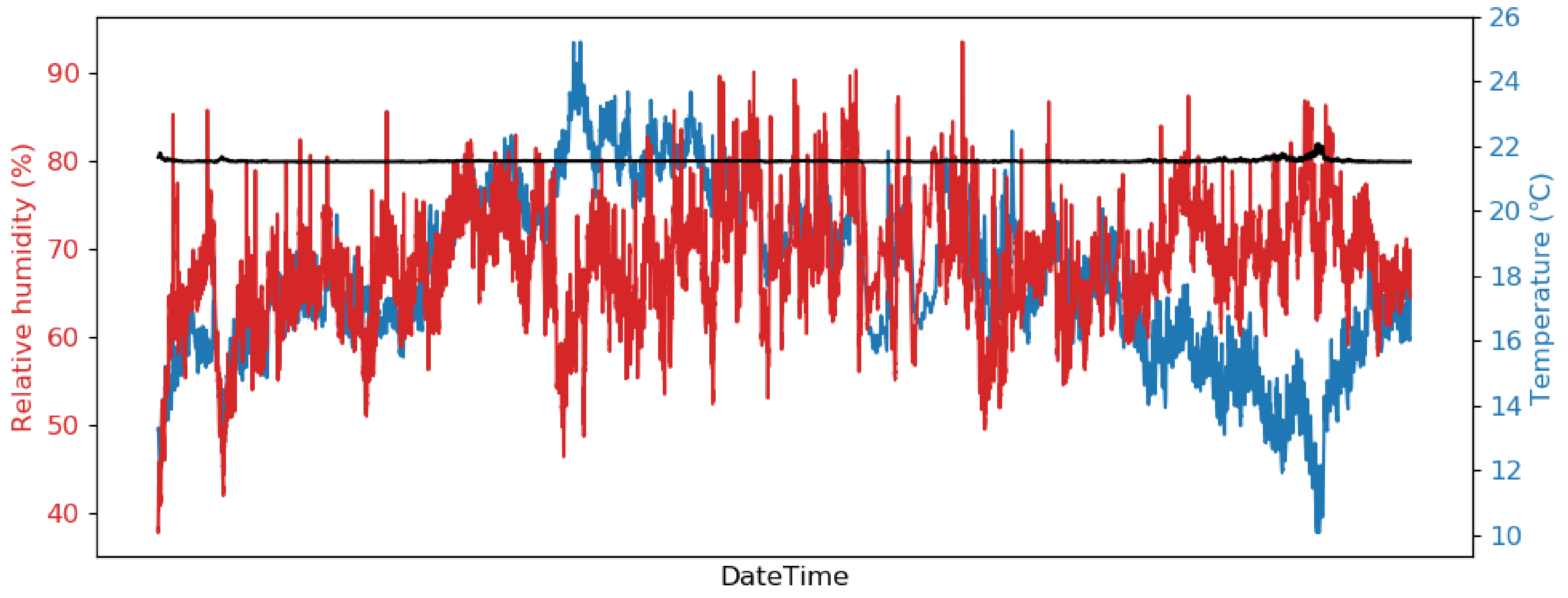
- 44% responded "Yes"

Has your home suffered from a mouldy/musty odour in last 12 months?

- 18% responded "Yes"

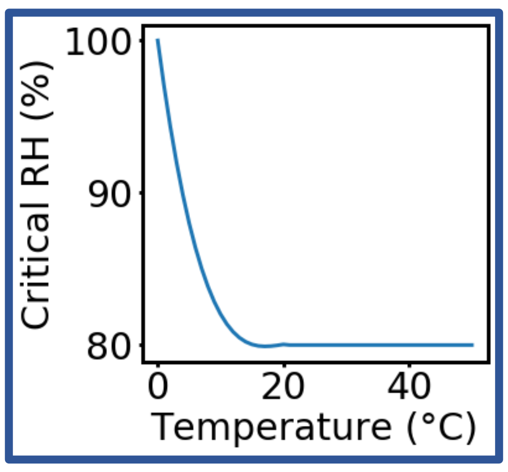
University of Exeter

Relative humidity and temperature



VTT model (Viitanen, 1997; Hukka & Viitanen, 1999)

$$RH_{crit} = \begin{cases} -0.0026T^3 + 0.160T^2 - 3.13T + 100.0 & when\ T \leq 20 \\ 80\% & when\ T > 20 \end{cases}$$



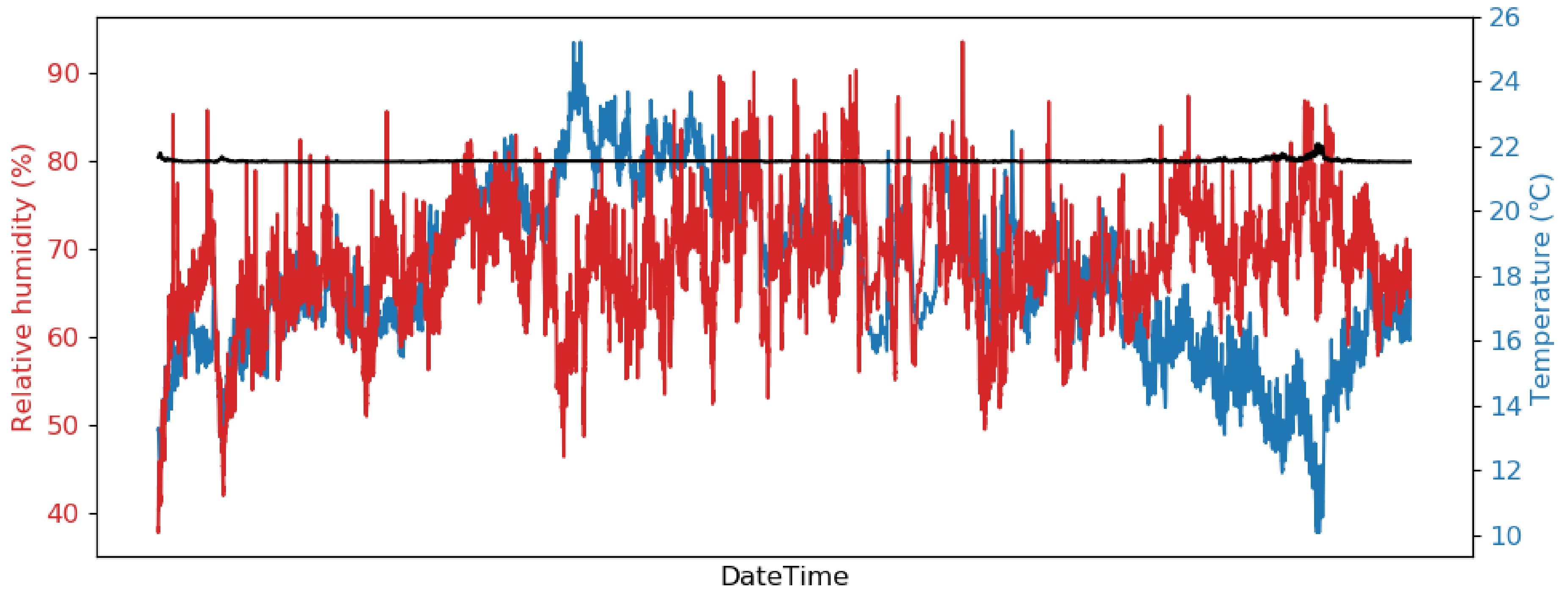
Current RH above critical level:

$$\frac{dM}{dt} = \frac{1}{7 \times e^{(-0.68\ln(T) - 13.9\ln(RH) + 0.14W - 0.33SQ + 66.02)}}$$

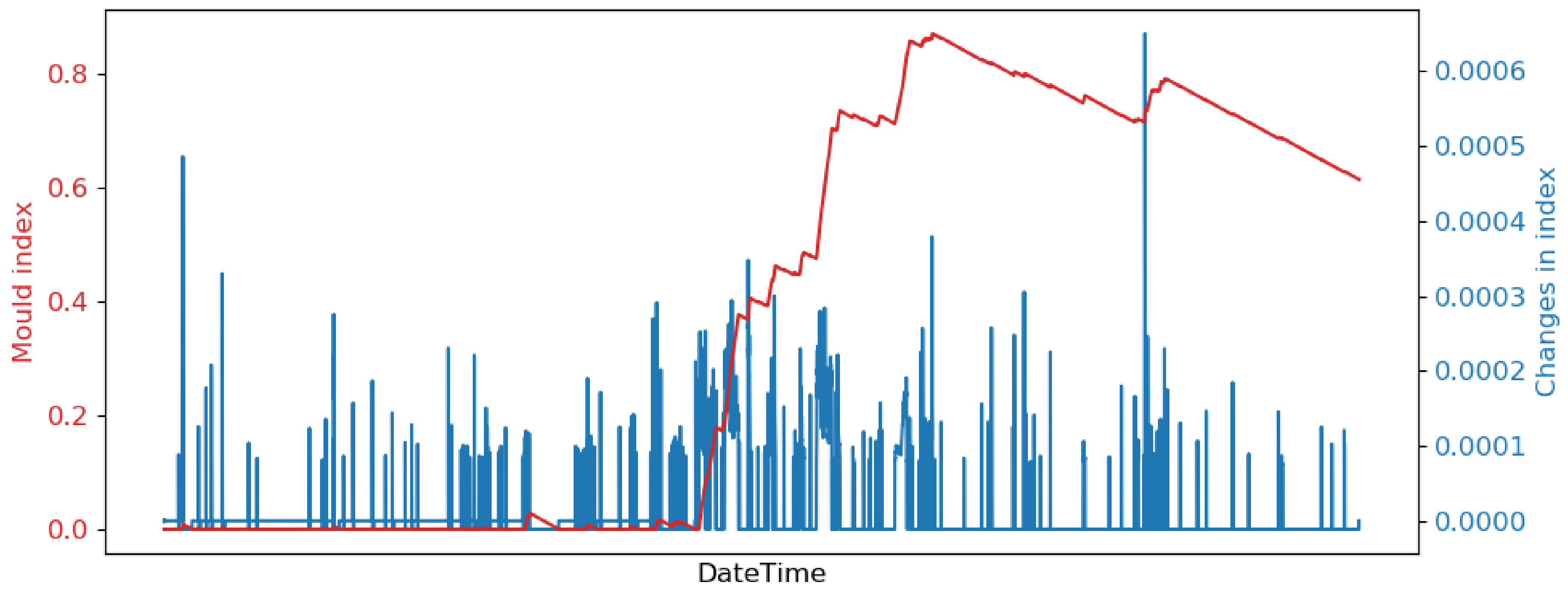
Current RH below critical level:

$$\frac{dM}{dt} = \mathrm{C_{decline}} \begin{cases} -0.032 & when\ t - t_1 \leq 6h, or\ for\ nonwood\ surface \\ 0 & when\ 6h < t - t_1 \leq 24h \\ -0.016 & when\ t - t_1 > 24h \end{cases}$$

Relative humidity and temperature



VTT output



VTT model (Viitanen, 1997; Hukka & Viitanen, 1999)

$$RH_{crit} = \begin{cases} -0.0026T^3 + 0.160T^2 - 3.13T + 100.0 & when\ T \leq 20 \\ 80\% & when\ T > 20 \end{cases}$$

Sensitivity

Time between readings

360 separate models:

- Each combination of model values
- Data from living room or bedroom

Current RH above critical level:

$$\frac{dM}{dt} = \frac{1}{7 \times e^{-0.68\ln(T) - 13.9\ln(RH) + 0.14W - 0.33SQ + 66.02}}$$

Current RH below critical level:

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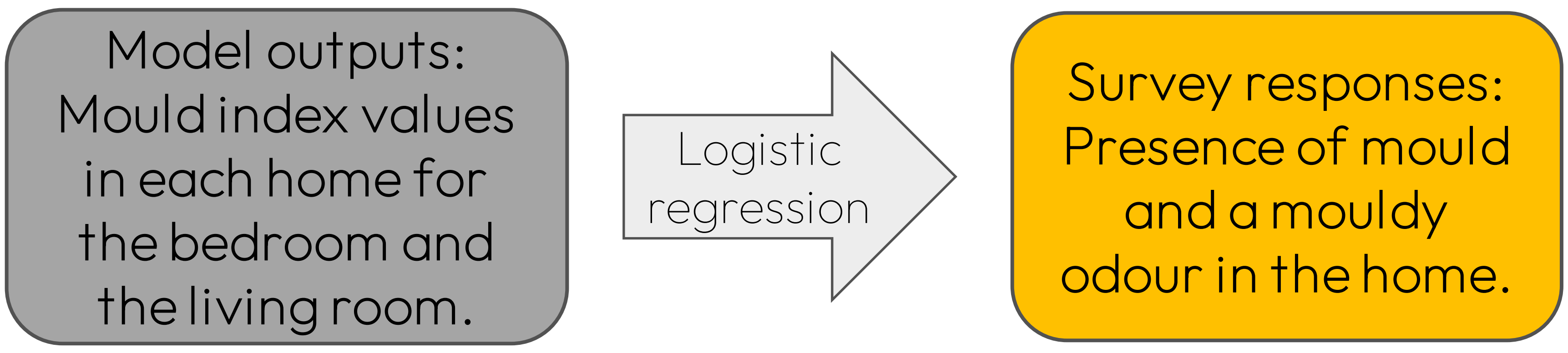
Parameter space 2

Parameter	Values
Resampling interval (minutes)	5, 60
Sensitivity	VeryX2
Default RH_{crit} (%)	**40, 45, 50, 55, 60, 65, 70, 75, 80**
Coefficient for T, pT	0.34
Coefficient for RH, pRH	6.95
Constant, pC	33.01
Method of decline	Wood (W), Non-wood (NW)
$C_{decline}$	0.1

Evaluating the model outputs



Survey = Mould

LR

	40	45	50	55	60	65	70	75	80
5 mins, W	0.200	0.157	0.007	0.040	0.029	0.078	0.322	0.983	0.718
5 mins, NW	0.212	0.101	0.012	0.052	0.081	0.163	0.551	0.812	0.457
60 mins, W	0.097	0.058	0.064	0.087	0.056	0.088	0.361	0.853	0.783
60 mins, NW	0.080	0.061	0.083	0.080	0.088	0.293	0.536	0.783	0.446

BR

	40	45	50	55	60	65	70	75	80
5 mins, W	0.724	0.172	0.072	0.123	0.180	0.080	0.405	0.556	0.596
5 mins, NW	0.652	0.180	0.029	0.187	0.115	0.283	0.319	0.757	0.658
60 mins, W	0.394	0.244	0.240	0.305	0.163	0.087	0.423	0.704	0.688
60 mins, NW	0.393	0.268	0.347	0.252	0.135	0.312	0.201	0.837	0.473

Survey = Odour

LR

	40	45	50	55	60	65	70	75	80
5 mins, W	0.372	0.196	0.028	0.062	0.082	0.052	0.029	0.030	0.114
5 mins, NW	0.614	0.167	0.030	0.075	0.110	0.057	0.033	0.043	0.862
60 mins, W	0.104	0.100	0.092	0.081	0.077	0.061	0.053	0.037	0.178
60 mins, NW	0.089	0.090	0.075	0.090	0.129	0.076	0.040	0.110	0.855

Colour scale: 0.0 – 0.2 – 0.4 – 0.6 – 0.8 – 1.0

BR

	40	45	50	55	60	65	70	75	80
5 mins, W	0.968	0.039	0.011	0.010	0.019	0.012	0.010	0.013	0.149
5 mins, NW	0.449	0.021	0.008	0.017	0.016	0.007	0.003	0.009	0.158
60 mins, W	0.060	0.030	0.021	0.018	0.019	0.017	0.017	0.017	0.210
60 mins, NW	0.059	0.030	0.020	0.022	0.016	0.006	0.003	0.007	0.185

Colour scale: 0.0 – 0.2 – 0.4 – 0.6 – 0.8 – 1.0

Survey response	Sensor data room	Default RH_{crit} (%)	p	TPR	TNR	Precision	Balanced accuracy	F1	Chance-level F1 (SD)	SDs above chance F1
Mould	Living room	50	0.012	0.833	0.431	0.594	<u>0.632</u>	<u>0.694</u>	0.671 (0.006)	3.896
Odour	Bedroom	50	0.008	0.769	0.652	0.333	<u>0.712</u>	<u>0.465</u>	0.335 (0.023)	5.688

Summary

- Model improved when made more sensitive
  - Critical RH <80%
  - Air versus surfaces
- Mould versus mouldy odour
- Adding value to sensor data
- Future smart control
  - Dynamic model

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Modelling mould growth in domestic environments using relative humidity and temperature

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