

# Experimental field-trial design to investigate the effects of a defective internal vapour layer on timber frame wall constructions including initial findings

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**Abstract.** Hygrothermal analysis in multi-layered building components is becoming common practice. Low energy design criteria demands an increase in thermal and airtightness requirements resulting in more complicated building envelope designs to accommodate the necessary insulation and airtightness layers. Furthermore, in many cases materials are being chosen based solely on their thermal characteristics without fully considering other properties and this may lead to unintentional interstitial moisture-related problems. Much progress has been made in developing tools for undertaking hygrothermal simulations; however, there are ongoing questions regarding how best to model imperfections and defects accurately using these software packages. Results of simulation models carried out in accordance with the new WTA guideline have been reported in literature as encouraging and confirming practical experience. Further verification of these simplified methods is therefore essential, including investigations of the relationship between model assumptions and typical defects in different construction types. Therefore, there is a need for specific field experiments and laboratory tests which gather the data necessary to validate and/or calibrate these models under a wider range of constructions types, defect types and climates. This paper describes the experimental design and fabrication of a full-scale timber frame test house that has been developed to assess the impact of a common defect in the internal vapour control/airtightness barrier, along with initial data results and findings. The data obtained will be used to validate existing commercial hygrothermal models and investigate different parameters and methods for modelling these vapour barrier defects.

## 1. Introduction

More stringent low energy building standards such as passive house and NZEB (Nearly Zero Energy Buildings) are resulting in higher performance requirements from building envelopes. It is now common for buildings aiming to achieve these standards to have walls

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up to 400mm thick. The Energy Performance of Buildings Directive adopted by the European Union requires all new buildings to be nearly zero energy by the end of 2020, with all new public buildings to reach the target by 2018 [1]. As a direct result of these high standards, and as thermal performance and air tightness requirements increase, so to do concerns about the risk of interstitial moisture movement leading to structural and health problems caused by rot and mould growth.

Moisture related issues are one of the most common building defects in both domestic and non-domestic construction today. Moisture sources inside and outside a building are abundant and therefore it is crucial that the building fabric is designed with adequate measures to provide appropriate protection against moisture damage. Uncontrolled moisture in building envelopes can have both structural and occupant health implications depending on the material composition of the building fabric. With timber frame buildings, extra care is required when designing the building fabric due to the risk of biodeterioration. Timber is a natural food source for fungi, which can break down the structural composition of timbers and can lead to the growth of mould which has been associated with human health problems. There is also heavy reliance on the quality of the workmanship, particularly with respect to the installation of the vapour control/airtightness layer. Typical 'weak points' in timber structures where moisture may penetrate include service penetrations, interfaces at window and door opes, interfaces with roofs/floors, interfaces with different structures, complex geometries and miscellaneous penetrations made over the duration of the building's lifespan (hanging pictures, shelves etc.).

Transient hygrothermal analysis tools are becoming more sophisticated and now represent the state-of-the-art in assessing the risks of moisture-related problems in multi-layered building components (walls, roofs, floors etc.). Previous steady state calculation methods such as the Glaser method are being superseded since modelling simplifications mean they cannot possibly accurately reflect the range of conditions that may occur over the life of a building. While the necessary analysis tools have now been developed and validated against many field and laboratory test results, it remains the responsibility of building designers to use these tools in the most appropriate manner with correct project specific assumptions, input parameters and variables. Moreover, the results of these analyses must also be interpreted correctly to be of value when designing a building fabric element.

A number of standards have been developed to provide guidance for undertaking this type of dynamic analysis [2]–[4]. The latest revision of WTA 6-2 (2014) describes a simplified method to account for unintentional convective moisture sources that are likely to occur in building components because of a defect in the vapour control layer. As the airflow paths for this type of defect are multi-dimensional and generally not known (every potential moisture/air leak will be different), the simplified approach introduces a moisture source within the construction accounting for the vapour convection and potential condensation at that point. The simplified model was developed by [5] through experimental tests and also checked for credibility by [6] with positive results reported. According to [7] initial simulations in accordance with the latest WTA guidelines are showing representative results, however improvements to these models can still be made which requires further investigations of the various possible defect types in various constructions subject to different climatic conditions.

## **2. Previous studies and tests**

Research on dedicated test houses which are constructed solely for such field tests, allow for a variety of different wall and roof assemblies to be tested, all under the same conditions and with a variety of known defects. A number of such test houses have been successfully

built and monitored (see, for example, [8]–[12]), providing valuable data for the validation of hygrothermal models and for design simulations. However, there are still few examples of test houses specifically aimed at monitoring and assessing the impact of a defective vapour control layer/airtight membrane.

It is important that the impact of defects or penetrations in building envelopes is fully understood to facilitate better detailing and design in line with the requirements for higher performing construction methods. This requires simulation models which have been validated using data from tests designed specifically to analyse the impact of these defects. It is also important that any derived ‘safety factors’ are based on practical experience in terms of what can be expected when constructing in accordance with best industry practice, as designers cannot be responsible for building fabric failures where the envelope has been poorly constructed, and failure would be the fault of the building contractor.

### **3. Aims and objectives of the study**

The aim of the study is to design and build a test house which comprises several timber frame wall sections with a view to assess the effects of representative vapour barrier defects and how these impact the various wall build ups. The wall sections have been chosen based on typical specifications that represent current timber frame constructions in Ireland and the UK (refer to **Table 1** for detail of each wall type). Specific objectives of the study include:

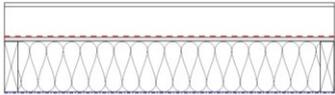
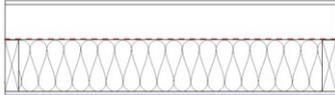
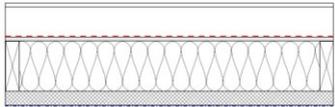
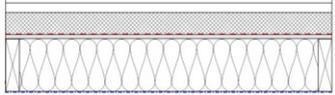
- review typical wall build ups and vapour defects in Ireland and UK;
- identify data input requirements for state-of-the-art transient hygrothermal simulation tools;
- develop a concept and detailed design for a representative test house;
- construct and commission the test house;
- collect and analyse the data obtained from the test house;
- use the obtained data for validation of a numerical model.

### **4. Methodology**

A full-scale experiment comprising multiple timber frame wall assemblies has been constructed to monitor the temperature, relative humidity and moisture content of the air and timber sections at selected locations within the wall build ups. The areas to be monitored have been chosen based on the most critical locations for high moisture conditions ([13] and [14]) and possible condensation risks that could lead to occupant health and building fabric issues i.e. toward the external side of the thermal line where temperatures are approaching the dew point.

The experiment comprises two wall modules for each chosen wall build up – one installed without defects (this shall represent the baseline case) and a second with a defective airtight/vapour control layer. The type of defect has been chosen to reflect common occurrences on site (based on feedback from practicing Architects, Engineers, Specialist Consultants and Contractors).

**Table 1.** Summary of wall types

WT1	11mm treated timber cladding ventilated cavity (40mm minimum) breather membrane <b>11mm osb board</b> 140x38mm treated timber stud (Norway Spruce) full fill mineral wool insulation vapour control layer	
WT2	11mm treated timber cladding ventilated cavity (40mm minimum) breather membrane 140x38mm treated timber stud (Norway Spruce) full fill mineral wool insulation <b>11mm osb board</b> vapour control layer	
WT3	11mm treated timber cladding ventilated cavity (40mm minimum) breather membrane <b>11mm osb board</b> 140x38mm treated timber stud (Norway Spruce) full fill mineral wool insulation <b>60mm PIR insulation</b> vapour control layer	
WT4	11mm treated timber cladding ventilated cavity <b>60mm PIR insulation</b> breather membrane <b>11mm osb board</b> 140x38mm treated timber stud (Norway Spruce) full fill mineral wool insulation vapour control layer	
WT5	11mm treated timber cladding ventilated cavity <b>60mm woodfibre insulation</b> breather membrane <b>11mm osb board</b> 140x38mm treated timber stud (Norway Spruce) full fill mineral wool insulation vapour control layer	

## 5. Test House design

### 5.1 Concept design and rationale

The experiment comprises a timber shed like structure, circa 5m(l) x 1.5m(w) x 2.6m(h). All 4 sides are insulated, with an insulated floor and roof incorporating a PVC based waterproof membrane finish. Access is provided in the form of a door on the short (south)

elevation. The experiment is located on the roof of the Energy Centre building in the Technical University Dublin Grangegorman Campus, with the test walls forming the experiment facing north west, primarily due to restrictions on site. The 3 flanking walls not collecting data comprise an insulated timber frame structure, ventilated cavity and a simple timber cladding finish. The experiment will last for 24 months initially, running from January 2018 - 2020 with a view to extending this for additional research purposes. Temperature, relative humidity and moisture content are being logged for the chosen points at hourly intervals over this time.

Results will be compared firstly to see how the baseline cases perform, and secondly what impact an unintentional moisture source has on the performance of the wall assemblies resulting from the defective air/vapour control layer. The pass/fail criteria will focus mainly on the moisture content of the timber elements, where anything above 20% will be further investigated. The lower the moisture content of timber means the wall has a more robust design with a greater drying potential.

For every wall type in the experiment there is an A and B sample constructed. The A samples are constructed in accordance with best industry practice with a high level of attention to detail regarding the sealing and continuity of the vapour control membrane/air-tightness layer. The B samples contain a purpose-built imperfection in the airtightness/vapour control membrane to reflect a workmanship error/construction defect. The imperfections are consisted throughout all wall cases, comprising a one metre long vertical cut in the Vapour Control Layer.

## 5.2 Test house envelope

The tested wall specifications forming the study represent common construction build ups for Ireland and the UK based on a desktop study and information received from some of the leading timber frame manufacturers in those locations. One compromise for the wall assemblies in the study was the outer cladding material which is commonly specified as handset brickwork in Ireland. It was not possible to include a brickwork outer leaf due to restrictions on the site of the experiment and so a timber outer cladding was adopted instead.

Feedback from manufacturers confirmed that their wall designs are typically chosen based on thermal performance, without significant consideration for hygrothermal performance. **Table 1** outlines each of the tested wall configurations in the test house. The ancillary walls, roof and floors were insulated with 100mm rigid insulation to maintain a continuous thermal envelope and minimise heat losses through adjacent construction elements.

## 5.3 Monitoring and data collection

The equipment for monitoring the wall and the internal environmental conditions is as follows:

- OmniSense G-3 wireless data acquisition gateway;
- OmniSense wireless sensors measuring the following parameters:
  - Temperature (°C)
  - Relative Humidity (%)
  - Wood Moisture Content (%WMC)

Sensor readings are transmitted wirelessly to the G-3 data acquisition gateway, which is connected to a dedicated and secure web server via an Ethernet connection. The

measurements can then be viewed through an online remote monitoring website using a secure password to access the data. The data is downloaded for cleaning, checking and analysis on a regular basis.

For internal conditions the same wireless sensors are used to log data for temperature and relative humidity. Additional sensors for temperature and relative humidity are incorporated in the weather station control panel (located inside the test house) and readings from this can be used as a comparison between the two sensor types to check periodically for sensor bias/drift.

## 5.4 Environmental conditions

External boundary conditions are being monitored for the following parameters via a dedicated weather station on the Energy Centre roof:

- Temperature;
- Relative humidity;
- Wind speed;
- Wind direction;
- Solar radiation (Global and indirect);
- Rainfall.

Internal boundary conditions are maintained as follows:

- Temperature 21-24°C
- Relative humidity 45-60%

The internal temperature is maintained using a thermostat-controlled heater. Background trickle ventilation is provided in the form of passive ventilators installed in the door panel, to maintain an RH in the order of 45-60% to represent typical residential conditions.

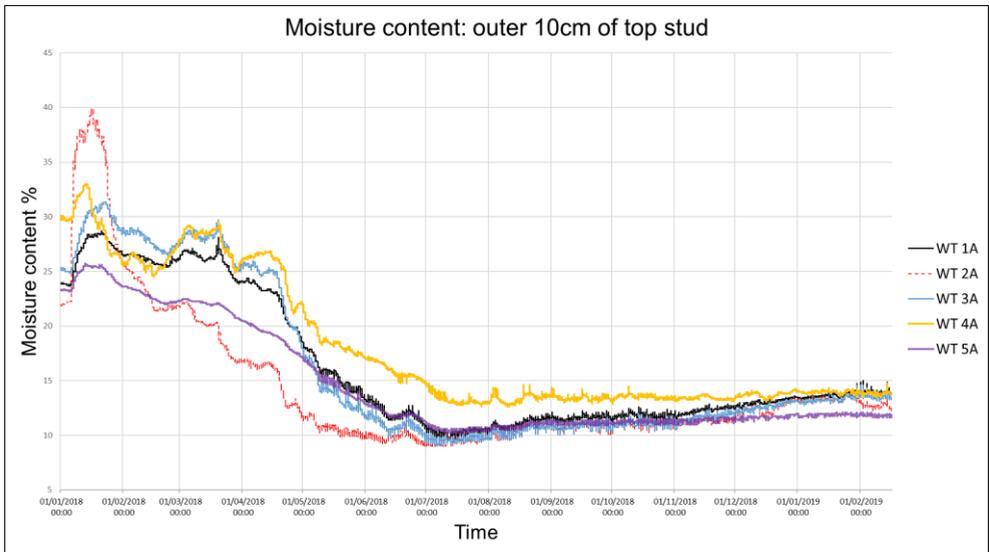
## 6. Preliminary results

The test house has been logging data since January 2018. Defects have been installed in the B samples since November 2018, which has allowed data to be collected for both A and B samples for each wall type under the same conditions to be used for verification purposes. The results below apply to the A samples only i.e. the wall panels without defects.

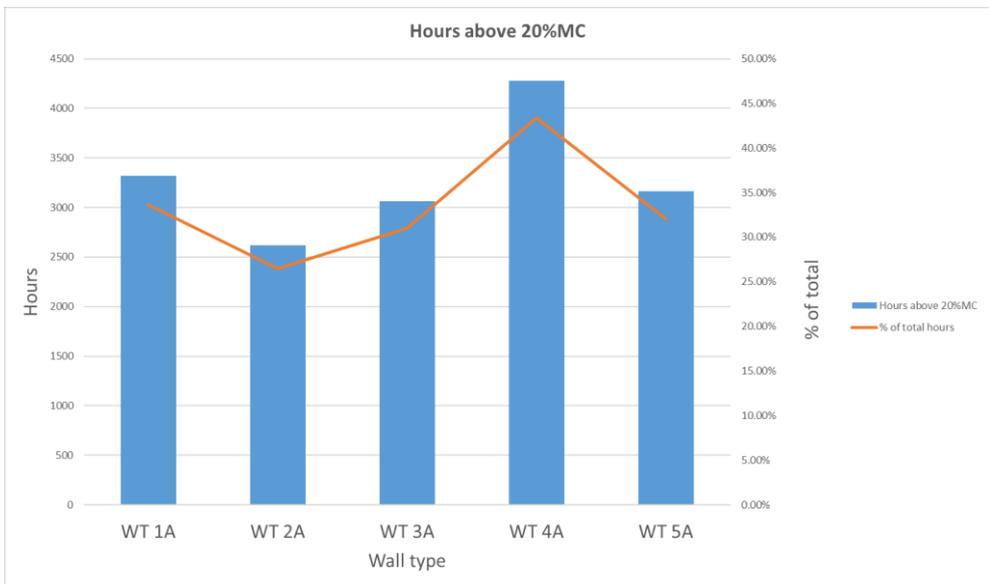
Fig. 1 below shows moisture content in the outer 10cm of the top horizontal timber stud for each of the wall types ('A' samples). The data covers January 2018 – February 2019. In January 2018 the effect of built-in construction moisture and moisture from weather conditions during construction is still resulting in high moisture content of the timber. This initial moisture decreases eventually in all wall types, however what is evident from the data is the rate of drying out varies for the different wall constructions. WT2A, being the most vapour permeable towards the outside, reaches a safe moisture content (<20%) in early March 2018. This wall type is the only one with the OSB situated to the inside face of the timber stud. WT1/3/4/5 all take longer to reach a safe moisture content (late April-May). These wall types all have OSB on the external side of the timber stud which restricts the drying out process.

Fig. 2 shows the number of hours each wall type spent above 20% moisture content, and how this translates into a percentage of the total number of hours of data. Again, WT2A performs well as a result of its increased vapour permeability towards the outside. WT4A is the most vapour resistant construction as it comprises OSB board on the external side of the timber stud along with additional PIR insulation to the front of the OSB which further

contributes to the walls overall vapour resistance and extends the number of hours spent above 20% moisture content.



**Fig. 1.** Moisture content in outer 10cm of top stud



**Fig. 2.** Number of hours above 20% MC

## 7. Conclusion

This paper describes the concept design and rationale for a timber-framed test house aimed at analysing the effect of a common vapour barrier defect on several typical timber frame wall assemblies representative of the UK and Ireland. The test house is logging data over an

initial period of 24 months. Following the data logging period, a comparison can be drawn between walls with and without a defect in the vapour control layer. Data can also be used to verify hygrothermal simulation models based on the latest recommendations in WTA 6-2 which account for unintended moisture sources in hygrothermal models.

The initial findings show WT2A has the greatest drying potential compared to the other wall types when exposed to moisture e.g. construction moisture. Although to date, all wall types reach a safe and stable moisture content, there is advantages to having a greater drying potential in timber frame walls to deal with possible future moisture ingress issues. The study outlines the importance of correct material selection and location within timber wall assemblies and that more robust constructions can be achieved if this is considered at early design stage.

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