Evaluating the present day ambient warming resilience of passively cooled dwellings in Ireland: A data-driven approach

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ABSTRACT

The use of the word "resilience" has increased significantly since 2010, however, there is a lack of understanding around 1) how thermal resilience is defined (where some definitions were offered only recently) and 2) what distinguishes it from typical overheating assessments. In addition to this, there is a lack of uptake in the remote monitoring industry (which uses low-cost solutions) when it comes to typical parameters used in thermal comfort studies and there is need to demonstrate how resilience performance can be reported going forward. To address or go towards addressing these gaps in the literature several case study buildings with low-cost measurement solutions are assessed according to both standardised approaches to overheating and regarding emerging resilience metrics in the literature. The aim of the study is to address what differences exist between standardised performance and resilience performance over time for buildings located in temperate climates which represent the best case for passive solutions. In this paper, hourly data from two A-rated residential buildings is analysed over several years with respect to outside conditions. The data logging systems are representative of typical "off-the-shelf" monitoring solutions on the market for residential applications in Ireland. A combination of standardised overheating metrics and emerging ambient warming resilience metrics are used to determine the thermal resilience of these buildings in present day conditions. The data logging solution tested in theory provided sufficient data, however, the use of residential Wi-Fi networks resulted in many dropouts which was found to be unfavourable. Current results indicate overheating incidences in both buildings but in different building zones. Despite these zones overheating, the use of ambient warming resilience metrics indicated that the buildings were able to supress outdoor stress passively ($a_{IOD} < 1$). The use of ambient warming resilience metrics was therefore found to aid in diagnosing the current suppressibility of the buildings passive systems. In addition to this, more work is needed in comparing low-cost solutions and research grade equipment to determine their suitability going forward. More work is needed in further exploring and refining additional field measurement-based resilience assessment methods and considering other variables and factors outside of ambient warming.

KEYWORDS

Thermal resilience, data-driven, overheating, passive cooling, assessment, ambient warming

1 INTRODUCTION

The vast majority of people in Ireland (85%) are concerned about climate change, with 37% describing themselves as "extremely concerned.", 47% believe that climate change is affecting them "right now," and 22% believe that it will begin to affect them within the next decade (Deignan et al. 2022). The truth is that climate change is already having a significant impact on businesses and various economic sectors, such as the building sector, and the magnitude of this impact will increase in the coming decades (IPCC 2021). Despite the fact that the impact of global warming is unknown and is contingent on future actions, the World Meteorological

Organization (WMO) and the United Nations Environment Programme (UNEP) have already predicted a warming of +4°C in Europe by 2100 (IPCC 2013). Many European countries have developed their building policies in recent years to include net zero energy buildings (NZEBs) as passive buildings and it is necessary to control potential indoor overheating in a future warming scenario (BPIE 2015). A recent review of existing thermal comfort (TC) indices and overheating (OH) metrics concluded that a new TC index for OH risk prevention is necessary (Carlucci and Pagliano 2012). According to McLeod et al., (2013), there are numerous well-insulated buildings whose occupants report experiencing high temperatures. Passivhaus (PH) is one of the most well-known design standards in Europe, having been implemented in thousands of buildings since 1991. According to a study conducted on a multifamily PH in the United Kingdom, 72% of monitored flats failed to meet design criteria, indicating that user behaviour plays the most significant role in increasing or decreasing the risk of OH (Sameni et al. 2015). There are numerous examples of OH prevention throughout Europe; some findings indicate that user strategies, such as ventilation and shading are critical for maintaining an acceptable level of indoor thermal comfort during hot periods (Mlakar and Štrancar 2011). In Irish context, there are a number of studies which indicate overheating in Irish dwellings built to both PH standards as well as in A-rated or high-performance dwellings (Colclough et al. 2018; Finegan, Kelly, and O' Sullivan 2020; Saini et al. 2020; Washan 2019). These studies indicate that overheating can be an issue in highly insulated dwellings with some reporting 41% of summer hours greater than 25°C in a living space (Saini et al. 2020). Others have also shown that tools used in the design of these can be inaccurate as they account for the whole building as opposed at the zone level (Finegan et al. 2020). Many have highlighted the need to update existing tools including upgrading the Dwelling Energy Assessment Procedure (DEAP) to account for OH or requiring a comprehensive "hour" analysis of OH at design stages (Washan 2019). Outside of these examples there are concerns that OH will get worse over time due to climate change. These concerns have led researchers to evaluate how resilient buildings are in current and future conditions (Hamdy et al. 2017; Sengupta et al. 2020). The overall aim of this study is to determine what differences exist between conclusions drawn from standardised overheating assessments compared and conclusions drawn using metrics used for typical assessments of building thermal resilience due to ambient warming. The secondary aims of the study are: 1) to determine the feasibility of completing such assessments using "off-the-shelf" sensors and low-effort approach and 2) what is required to improve data-driven thermal resilience assessments for these buildings in the future.

2 MATERIALS AND METHODS

2.1 Evaluation Metrics

There are numerous metrics and indices used in the assessment of indoor overheating (OH) likelihood in the context of buildings in general. These have been well documented by numerous authors (Colclough et al. 2018; Psomas et al. 2018), a summary of such metrics that are typically used for the purposes of OH evaluations are presented in Table 1. Metrics that consider the thermal resilience of buildings are emerging and the most comprehensive of these regarding thermal resilience is the work of (Sun, Specian, and Hong 2020) who presented a review of resilience metrics to evaluate the thermal resilience of buildings. In this work, two types of metrics are proposed: 1) simplified biometeorological indices and 2) complex indices. The simplified biometeorological indices are based on air temperature or a combination of air temperature and humidity. On the other hand, heat-budget models include the critical meteorological and physiological parameters needed to describe the physiological heat load: air temperature, water vapour pressure, wind velocity, and short and long-wave radiant fluxes.

Table 1: Typical criteria that are relevant to overheating evaluations in residential buildings.

Standard/Publication	**Criteria**	**Reference**
Passive House Standard	$T_a^* > 25$°C for 10% of the time	(Colclough et al. 2018; Passive Haus Institut 2019)
CIBSE TM36	$T_o > 28$°C for 1% of occupied hours $T_o > 25$°C for 5% of occupied hours	(Colclough et al. 2018) (Colclough et al. 2018)
CIBSE TM59	***Naturally ventilated***	
	1) Number of hours where $\Delta T \geq 1$ should not exceed 3% of occupied hours (May to Sept.)	(CIBSE 2017)
	2) Operative should not exceed 26°C for more than 1% of annual hours (between 10pm and 7am)	(CIBSE 2017)
	Mechanically ventilated	
	Operative should not exceed 26°C for 3% of the annual occupied hours	(CIBSE 2017)

T_a = air temperature, T_o = operative temperature, *For NZEB or low energy buildings T_o and T_a are assumed to be equal

An example of a simple biometeorological index that has been used in the context of buildings is the Heat Index (HI) shown in Equation (1) as indicated by (Board of Trustees of the University of Illinois, Laboratory, and Regents of the University of California 2022).

$$\text{Heat Index (HI)} = (-8.78469475556) + (1.611394411T) + (2.33854883889R) + (-0.14611605TR) + (-0.012308094T^2) + (-0.0164248277778R^2) + (0.002211732T^2R) + (0.00072546TR^2) + (-0.000003582T^2R^2) \qquad (1)$$

Where the HI is described by multiple linear regression equation based on the air temperature T (in °C) and the relative humidity R (in %). Table 2 indicates the typical ranges of HI that are considered and what negative health consequences are likely for different ranges of HI.

Table 2: Definition of four levels of Heat Index (taken from (Illinois and California 2021)).

Heat Index in Celsius	**Heat Index Level**	**Colour code**
Less than 26.7 °C	Safe: no risk of heat hazard	🟩
26.7 °C - 32.2 °C	Caution: fatigue is possible with prolonged exposure and activity. Continuing activity could result in heat cramps.	🟨
32.2 °C - 39.4 °C	Extreme caution: heat cramps and heat exhaustion are possible. Continuing activity could result in heat stroke.	🟧
39.4 °C - 51.7 °C	Danger: heat cramps and heat exhaustion are likely; heat stroke is probable with continued activity.	🟧
over 51.7 °C	Extreme danger: heat stroke is imminent.	🟥

In addition to these metrics some authors have considered the sensitivity of buildings to overheating incidences or climate warming, as well as consideration for the change in outside conditions (Hamdy et al. 2017; Rahif et al. 2021).

$$\text{IOD} = \frac{\sum_{z=1}^{Z}\sum_{i=1}^{N_{occ(z)}}\left[\left(T_{in,o,z,i}-T_{comf,z,i}\right)^{+} * t_{i,z}\right]}{\sum_{z=i}^{Z}\sum_{i=1}^{N_{occ}} t_{i,z}} \qquad (2)$$

The IOD (in °C) is the summation of positive values of the difference between zonal indoor operative temperature $T_{in,o,z,i}$ and the zonal thermal comfort limit $T_{comf,z,i}$ averaged over the sum of the total number of zonal occupied hours $N_{occ}\ (z)$, where t is the time step (in this case one hour), i is occupied hour counter, z is building zone counter, and Z is total building zones

(Hamdy et al. 2017). The AWD (in °C) metric (shown in Equation (3)) is used to quantify the severity of outdoor thermal conditions by averaging the Cooling Degree hours (CDh) calculated for a base temperature (T_b) of 18 °C, over the total number of building occupied hours, where $T_{out,a,i}$ is the outdoor dry-bulb air temperature and N is the total number of building occupied hours, where only the positive values of $\left(T_{out,a,i} - T_b\right)^+$ are taken into account in the summation. In addition to a base temperature of 18°C, a base temperature of 14°C was also considered as the buildings that were monitored were highly insulated (Rahif et al. 2021). It has been proposed that the IOD and AWD be combined to reflect the sensitivity of buildings to overheating using an overheating escalation factor (a_{IOD}) see Equation (4).

$$\mathrm{AWD} = \frac{\sum_{i=1}^{N}\left[\left(T_{out,a,i}-T_b\right)^+ t_i\right]}{\sum_{i=1}^{N} t_i} \tag{3}$$

The overheating escalation factor metric has been used previously to estimate the sensitivity of dwellings to overheating (Hamdy et al. 2017). It represents the variation in the indoor temperatures when they exceed a chosen thermal comfort temperature limit in each time-period (IOD) because of the severity of outdoor warmness, represented in this case by the AWD.

$$a_{IOD} = \frac{IOD}{AWD} \tag{4}$$

If the relationship between IOD and AWD is suitably representable with a linear regression model, the a_{IOD} will be the slope coefficient of the regression line. An overheating escalation factor greater than the unit ($a_{IOD} > 1$) means that indoor thermal conditions get worse when compared to outdoor thermal stress. On the contrary, an overheating escalation factor lower than the unit ($a_{IOD} < 1$) means that a dwelling can suppress some of the outdoor thermal stress.

2.2 Example buildings

This study considers two residential buildings, both located in Ireland. One building is in the midland's region of Ireland (referred to as Inland), the other is located on the southwest coast (referred to as Coastal). Both buildings are detached A-rated buildings according to Irish energy performance certificates and both have high performance envelopes (U-value of walls < 0.20 W/m^{2}K, roofs < 0.14 W/m^{2}K, floors < 0.13 W/m^{2}K, windows <1.50 W/m^{2}K). The Inland case study was a retrofitted building, the coastal case study dwelling was a passive house certified dwelling and so air-tightness air change rates (measured at 50Pa) varied for each building (Inland = 3.81^{-1} @50Pa, Coastal = 0.60^{-1} @50Pa). Both buildings were equipped with mechanical ventilation heat recovery (MVHR) units which had summer bypass modes, triggered when the exhaust air temperature inside the duct was greater than 25°C. Both were equipped with air-source heat pumps for heating and used natural ventilation (NV) for cooling (O'Donovan and O'Sullivan 2021; O'Sullivan et al. 2021). Two zones were monitored in both buildings, one bedroom and living zone in each building respectively. The living room zone in Inland dwelling consisted of a living space coupled with a kitchen and had over 18m^2 of external air-filled double glazing (SE = 6.2m^2, NE = 7.5m^2, SW = 4.4m^2) where over 45% of all glazing area was openable using mostly side-hung windows and one large sliding door, with no external shading devices. The bedroom zone of the Inland case study had one 3.7m^2 window that was northwest facing, there were also no external shading devices in this room, however, there were more substantial internal slated venetian blinds. No overheating indicators were used in the design of Inland dwelling. The coastal case study used Passive House Planning Package (PHPP) to factor in overheating and predicted 2.8% of internal temperatures greater than 25°C. The living room space is largely west facing and has over 14m^2 of external triple glazing, where approximately $4.4m^2$ of this glazing is openable with a sliding door on one side. There are some overhangs on the west façade which case a shading effect. The living room is connected to a kitchen space which has a stack ventilation system. The bedroom zone studied in the coastal dwelling had $9.1m^2$ of external triple glazing ($S = 5.1m^2$, $E = 4.0m^2$) where there is one openable window ($0.7m^2$) on the east elevation, again similar overhangs were present for windows in the bedroom zone.

2.3 Equipment locations, data specifications, and general approach

Both case study buildings had Netatmo weather stations (Netatmo 2020) installed with measurements being taken in living spaces and bedrooms. Quoted accuracies for these instruments were: ±0.3°C for temperature, ±3% for relative humidity and ±50ppm for CO_2 (Netatmo 2020). Measurements were conducted over two years from February 2020 to mid-December 2021 in the Inland dwelling, and over four separate years from January to December in 2017, 2018, 2020, and 2021 in the Coastal dwelling. Two rooms were monitored in each building (one bedroom and one living room space). Both internal and external datasets from Netatmo systems were downloaded at 30-minute intervals and averaged hourly. This dataset was merged with data from the nearest meteorological station (Met Éireann 2021). The analysis was conducted using RStudio version 4.1.0. To calculate the heat index the “weathermetrics” library was used as was indicated by (Brooke Anderson, Bell, and Peng 2013). Considering the standardised metrics and emerging resilience metrics described the approach of this paper is to adopt a similar approach to (Hamdy et al. 2017), however, instead of simulating the relationship between internal and external warmth, the data described above is used instead, which is historical data for varying external and internal conditions.

3 RESULTS AND DISCUSSION

3.1 Background climate

The climate in Ireland has been seen to be particularly suitable to passively cool year-round in current and future conditions (Bravo Dias, Soares, and Carrilho da Graça 2020; O’ Donovan, Murphy, and O’Sullivan 2021).

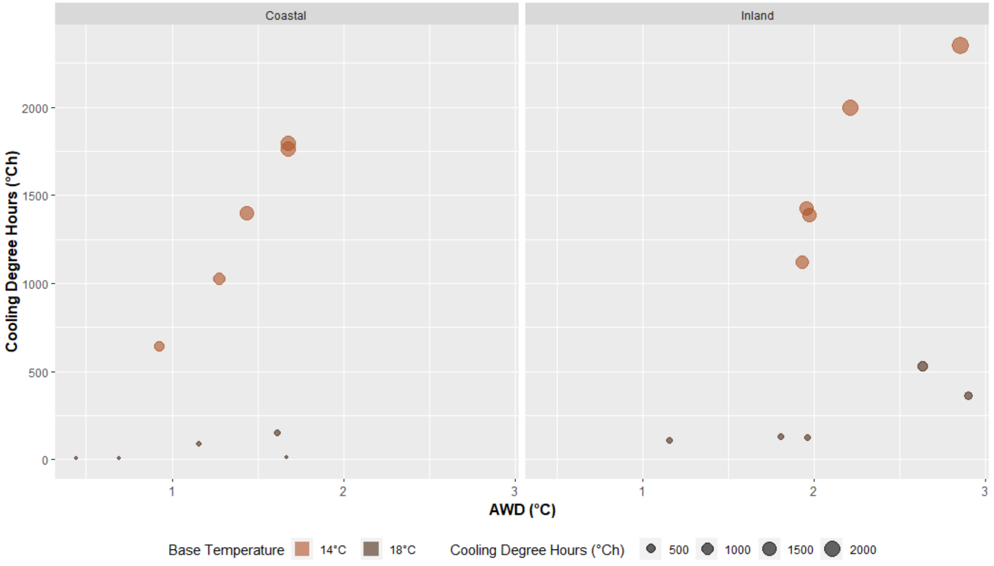

Figure 1: Ambient warmness degree (AWD) with respect to cooling degree hours for both locations from 2017 to 2021. (Size indicates the cooling degree hours, colour indicates base temperature used)

Despite both locations being relatively mild and classified as the sample global climate, locations in the midlands region of Ireland are likely to experience higher temperatures that those near the coast, exceeding 25°C in the Inland location and no observed exceedance of 25°C in the coastal location. In 2018 and 2021, there were over 60 hours in the year where external maximum air temperatures exceeded 25°C in the Inland location (see Figure 1). Figure 1 indicates the climate warming based on other metrics from a resilience perspective. Based on previous definitions for Dutch residential buildings which highlight and AWD of greater than 3°C as a risk (Hamdy et al. 2017), it is evident that warming in the Inland region is likely to be approach levels that could be risky. The same degree or severity of warming is not present in the coastal location which has had some years with zero CDHs. When the HI is used to determine the health risk there are very few periods of time since 2017 when conditions in the Inland region were likely to cause fatigue depending on activity levels. Based on these climactic indicators it is likely that the years considered (2018, 2020, 2021) should result in overheating incidences and may serve as good comparison years to demonstrate the severity of OH in the dwellings considered.

3.2 Overheating and thermal resilience

Table 3 presents a summary of the results for bedroom and living room zones in both case study buildings using typical comfort or OH metrics and indices used in reference to resilience studies. Regarding overheating, it is evident that the living room in the inland location overheats consistently in 2020 and 2021, and equally the performance of the bedroom in the coastal location is also undesirable. Both spaces fail the OH criteria for CIBSE and for reasonable levels of comfort for those with a high-level of expectation from EN 16798-1.

Table 3: Performance of each zone with respect to different metrics during occupied time (all seasons were included occupied hours were considered between 6pm and 7am, bold indicates values that exceed categories described in Table 1, grey indicates calculations that were not applicable).

Metric	Units	Inland				Coastal							
		2020	2021	2020	2021	2017	2018	2020	2021	2017	2018	2020	2021
		Bedroom		Living		Bedroom				Living			
T_{25}	%	0.0%	0.8%	**7.6%**	**11.2%**	1.9%	3.4%	4.6%	**7.9%**	0.0%	0.0%	0.0%	0.1%
T_{26}	%	0.0%	0.0%	2.7%	**4.0%**	0.4%	1.4%	2.0%	**4.2%**	0.0%	0.0%	0.0%	0.0%
T_{28}	%	0.0%	0.0%	0.0%	0.6%	0.0%	0.2%	0.3%	**1.1%**	0.0%	0.0%	0.0%	0.0%
Cat I	%	0.0%	0.0%	**4.8%**	**4.5%**	1.5%	2.5%	**3.6%**	**5.9%**	0.0%	0.0%	0.0%	0.0%
AWD_{18}	°C	1.5	2.0	1.5	2.9	1.7	1.3	0.7	1.6	1.7	1.3	0.7	1.6
AWD_{14}	°C	1.9	1.8	1.9	2.2	0.9	1.6	1.3	1.7	0.9	1.6	1.3	1.7
IOD_{26}	°C			0.5	1.1	0.7	1.0	1.1	1.4				
$IOD_{Cat\ I}$	°C			0.8	0.8	0.6	1.0	1.1	1.3		0.7		

The extent of this overheating also indicates increasing degrees of overheating year-on-year between 2017 to 2021. However, both buildings also have zones in their buildings that do not overheat despite being exposed to the same degree of ambient warmness (or AWD). The degree of OH according to an adaptive relationship (shown in Figure 2) shows considerable overheating in these zones that would indicate that they have an unacceptable thermal environment according to these standards. This figure indicates the variance in OH at zone level, despite both zones in each respective building being in exposed to the same degree of ambient warmness. This supports the observations of (Psomas et al. 2016) where it is clear that local overheating is more likely to be an issue in these types of buildings. Figure 2 also indicates the need for OH assessment to include seasons that are non-typical to cooling seasons and existing standards (i.e. May to September).

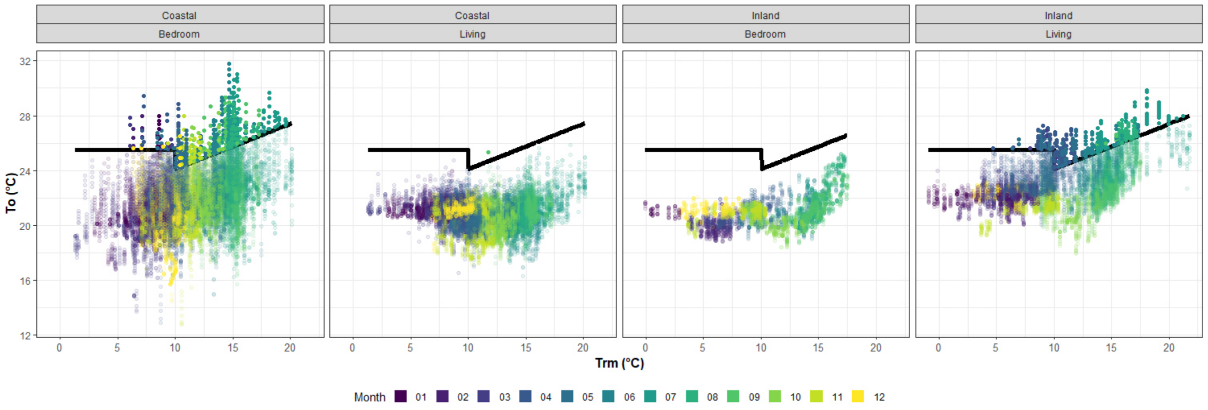

Figure 2: Scatterplot of exponentially weighted external mean with respect to the indoor operative temperature, using the adaptive model applied to both case study buildings during all measurement periods combined considering seasons outside of summer. (Black line indicates upper threshold for Category I of EN16798-1, colour indicates month of the year, while the data point clarity indicates values below the upper threshold or not).

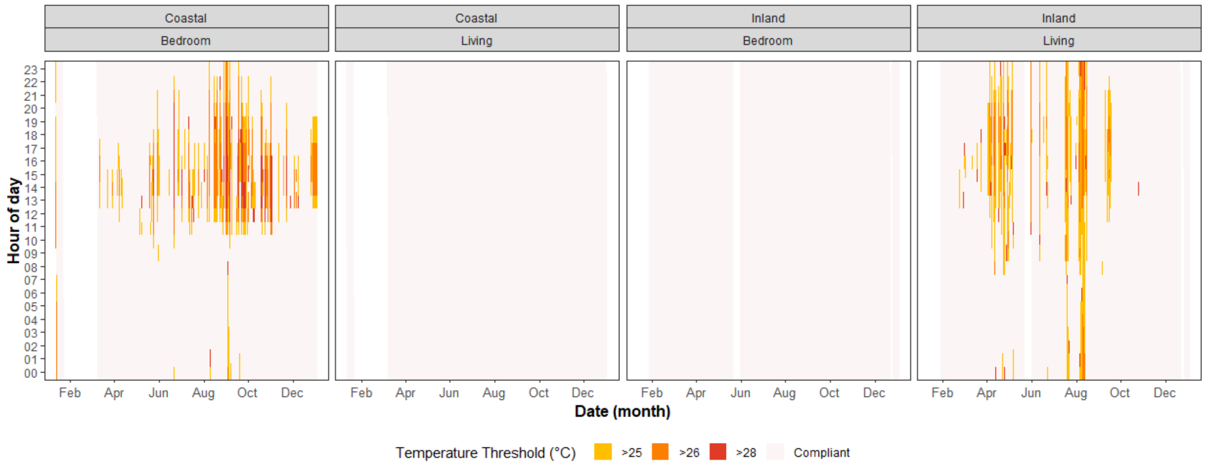

Figure 3: Heat maps for each room during 2020 (Colour indicates operative temperatures in excess of threshold indicated, compliant refers to operative temperature less than 25°C).

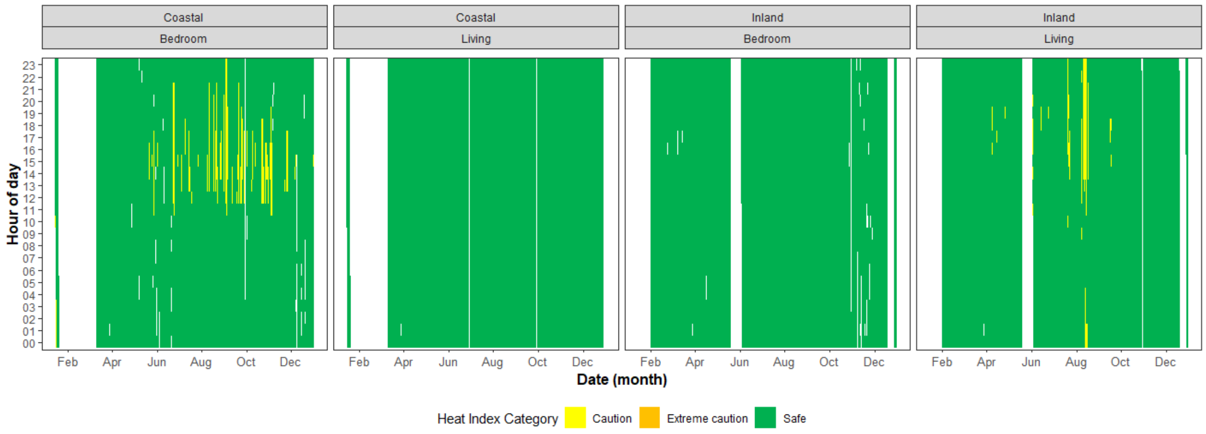

Figure 4: Internal HI for bedroom and living spaces in both case study buildings during 2020 (Colour indicates the hazard level).

For the coastal dwelling OH incidences occur in many months that are outside of the peak of the summer, but also in winter months. Figure 3 indicates that there can be very high temperatures in both the bedroom of the coastal dwelling and the living room of the inland dwelling, which occurs predominately in the afternoon and evening. There are few incidences of OH from 10pm to 7am in the bedroom of the coastal dwelling. Figure 4 indicates the likely amount of heat stress in each zone (considering both temperature and humidity), which would be a non-typical metric used in OH assessments. Using the HI, we can see that there several periods during the daytime where caution (and smaller occurrences of extreme caution) is required when entering both bedroom and living spaces. This occurs despite external HI conditions being largely "safe" during 2020. The reporting of this index shows that more caution should be taken by occupants than might be expected given the outside conditions. In addition to this, is also evident that this is a zone level experience, and that there is a risk for occupants in one zone of each building and not in the other. Figure 5 indicates the likely resilience of these environments that have overheated in their respective years. In this figure, the IOD and AWD from this study is plotted against the work of (Hamdy et al. 2017). The two lines of best fit from Hamdy's work indicate: 1) the relationship between IOD and AWD when the ventilation rate is maximised and an adaptive comfort threshold is used (in green), and 2) the same relationship when a minimum ventilation rate is applied and a static comfort threshold is used (in yellow).

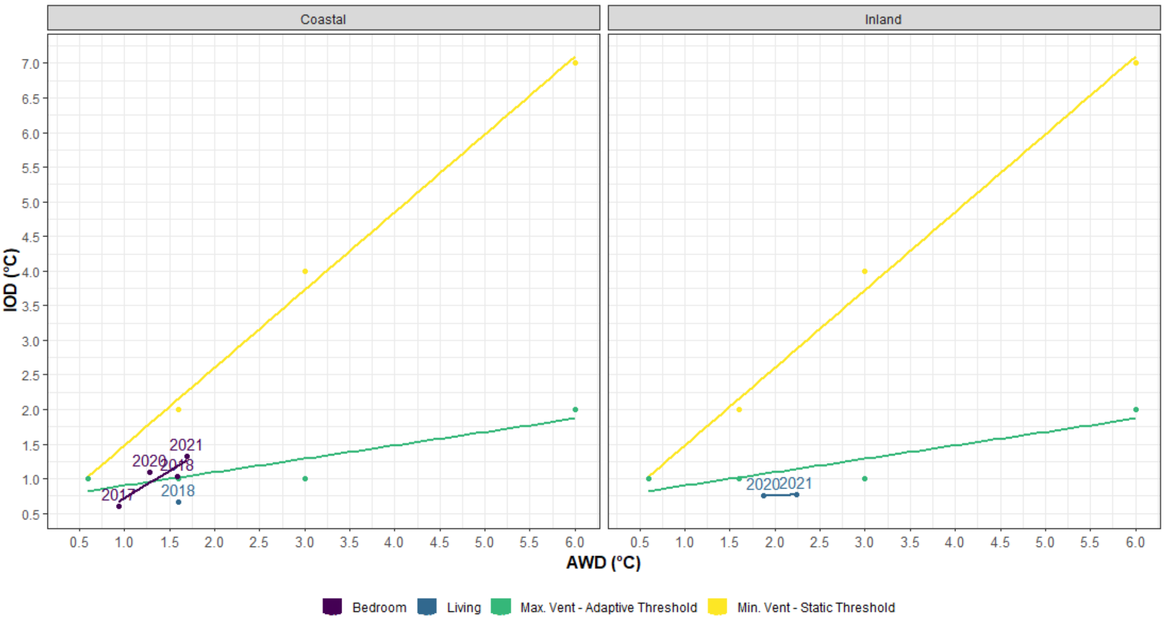

Figure 5: Scatterplot of AWD_{14} with respect to IOD_{CATI} for different zones in both case study buildings (Text indicates year, colour of smoothed lines of best fit and points represent zone type and reference values from (Hamdy et al. 2017) for a minimum ventilation scenario and a fixed threshold and a maximum ventilation scenario with an adaptive threshold).

These represent the range of best and worst cases from previous work with reference to the work in this study. Overall, the overheating escalation factor shows despite high OH incidences in the bedroom of the coastal dwelling and the living room of the inland dwelling that their respective escalation factors are 0.78 and 0.02 respectively. Considering the relationship between IOD and AWD, what is clear is that in this incidence, (despite changes in AWD) the sensitivity of these structures to overheating over many years indicates that passive cooling can supress a good portion of the warmth of the external climate sufficiently ($a_{IOD} < 1$).Considering these with reference to the work of (Hamdy et al. 2017) we can see that most IOD values are closer to the suppression slope of less than 1 and closely follow the maximum ventilation and adaptive threshold scenario (indicated in green, with a slope of 0.19), however, the trend in the bedroom of the coastal dwelling indicates that more interventions may be needed in this zone. The lack of overheating in some zones also points to suppression of OH despite increasing ambient warmness. It should be noted that when a typical IOD and AWD (i.e. AWD_{18} and IOD_{26}) relationship is drawn as indicated by (Hamdy et al. 2017) this also leads to escalation factors (or slopes) which are -0.04 and 0.36 for coastal and inland dwellings respectively which indicate a general suppression of excess heat also.

3.3 General discussion

The following assessment using both ambient warming resilience and overheating metrics indicates that it is feasible to account for resilience using measured data, however, there are many drawbacks to data-driven approaches such as data dropouts which can be significant even with industry standard systems (O'Donovan, O'Sullivan, and Murphy 2017). More work is needed to integrate existing metrics into cloud-based platforms to allow for the creation of dashboards or decision support tools so action can be taken in buildings in advance of future extreme conditions. Despite there being some evidence to suggest that the difference between air temperature and mean radiant temperature are negligible during most periods (Walikewitz et al. 2015), differences are likely to exist depending on different room characteristics. There is a need to compare different low-cost sensor enclosures and their suitability in measuring the operative temperature. The high temperatures observed here in the bedroom of the coastal dwelling was indicated by homeowners as being due to the incorrect installation of reflective coatings leading to higher surface temperatures. It should also be noted that the MVHR units in each building rarely trigger summer bypass mode despite high levels of overheating in specific zones. This is likely due to the mixing of air from zones where there are no overheating issues with those that are overheating. The lack of a summer bypass may be contributing to the overheating issue in the living room of the inland dwelling, as this has been seen to be a contributory factor to OH in dwellings (Morgan et al. 2017), however the cooling benefit may be limited (McLeod and Swainson 2017). Regarding future resilience assessments, it should be noted that there can also be a limitation as to the number of years considered (Hamdy et al. 2017; Ramin Rahif et al. 2021) use four years (with more than one year between years) when drawing relationships, clearly drawing conclusions from two points is not as reliable as four, this should be considered in future assessments, for example what is the centrality of the IOD and AWD relationship and what value can be had using different metrics when referring to indoor heat and outdoor heat. More consideration should also be given to the amount of averaging data as part of AWD and IOD used, a small number of data points greater than the 18°C and 14°C threshold can lead to average IOD values that are not representative, given its consideration of positive values only. The value of the resilience assessment in this application case is that is highlights the likely increases in internal conditions under foreseen warm ambient conditions which provides insights into which zones are likely to experience more OH risk in the future. The extension and use of the heat index and its incorporation into IOD and AWD calculations could also be of benefit. The overall OH indicates a need to consider OH and NV at design stage and including additional ventilation and shading choices into the DEAP methodology.

4 CONCLUSIONS

In this study we present and overheating assessment of two A-rated homes in Ireland using a data-driven approach and compare this to an ambient warming resilience assessment using the same data. Although OH assessments indicate which zones in each building are overheating, the use of ambient warming resilience-based assessment provides insights into the extent of this overheating over time and what the likely sensitivity of a building’s zones are to ambient warmness. The work presented here shows that this assessment is feasible using a data-driven approach, however, more work is needed in providing additional diagnostics and explaining the factors that are likely to contribute to varying sensitivities, as well as assessing the need for additional variables and comparative assessments of the accuracy of existing low-cost systems over time. In addition to this, more work is needed in further examining the applicability of different IOD values, the required dataset quantities as well as determining more suitable methods for identifying threshold values when considering ambient warmness. Varying metric thresholds (adaptive and static) and varying warmness thresholds can lead to different sensitivity values. Future “off-the-shelf” solutions should focus on improving data quality as well as incorporating the metrics discussed. Despite both buildings having zones that overheat both zones can supress this heat and if additional measures are used to reduce solar loads both may be resistant to ambient warmness in current conditions.

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