St. Mary and St. Anne Cathedral, Cork:

An optimum heating solution for heritage buildings?

Christopher Shiell, Roger P. West
Department of Civil Structural and Environmental Engineering, Museum Building, Trinity College, University of Dublin, Dublin 2, Ireland
email : shiellc@tcd.ie, rwest@tcd.ie

***ABSTRACT*:** Cathedrals and most churches are characterised by having large internal, undivided spaces and permeable building envelopes. They are often used little or intermittently, but predictably and, in spite of the fact that they are unique in still being largely used for the purpose for which they were built many centuries ago, they are now often used for additional purposes, for which they were never designed. These uses include concerts, graduation ceremonies, filming and a host of other uses all of which require a level of thermal comfort not envisaged by the original builders. Research was undertaken by the authors into the internal thermo-hygrometric environment in the 57 active cathedrals in Ireland. 25 of these cathedrals were monitored for both temperature and relative humidity variations for at least one month during the heating season from which over 2.5 million readings were recorded and analysed. Various heating solutions are employed in the cathedrals, with the most common being low pressure hot water, which is used in 36 cathedrals or 63% of the total. One of the monitored cathedrals was St. Mary's in Cork, which is the only cathedral with a gas powered, hot air blower supplemented by a number of small radiant heaters to enhance the blower system. This produces a very fast heating up and cooling down rate, in excess of 20˚C per hour (compared to 1 - 3ºC per hour normally) with corresponding falls and rises in relative humidity. As the fabric's thermal mass and subsequent lag are not relevant in this instance, there is little or no waste of energy and heating is turned on only shortly before events, unlike the typical 4-5 hour heat up time required by many cathedrals. Irish cathedrals are 100% fossil fuel dependent with no plans to be otherwise. If a way could be found at St. Mary's cathedral to use renewable energy to drive its heating system, it may well create the optimum solution for this type of building, of which over 3,800 exist on this island.

KEY WORDS: Cork, cathedral, heating, heritage, sustainability, renewables

1 INTRODUCTION

On 3rd February 2017 it was announced that one of the largest churches in Ireland in Finglas West, with a seating capacity of 3,500, was to be demolished and replaced with a church with a seating capacity of 350. One of the reasons given for this was 'high maintenance and running costs' [1]. Congregations are both ageing and reducing and yet costs are rising. The Irish Times newspaper [2] printed extracts from a Towers Watson report, which had been commissioned by the Roman Catholic Church, showing a reduction in Mass attendance in Ireland between 2008 and 2014 of 20% and with a projected reduction between 2008 and 2030 of 47%. Irish census figures show a reduction of Roman Catholics attending Mass from 91% in 1972 to 33% in 2011 [3]. The shrinkage in numbers will lead to fewer services which will, amongst other changes, result in a change to the internal thermal environment in churches and cathedrals. Empirical evidence suggests that the Church of Ireland is also being affected by ageing and reducing congregations. Roman Catholic churches do not permit [4] use of their buildings for anything other than religious events, whilst the Church of Ireland does allow the use of its buildings for secular events, which it does to raise revenue. The use of church buildings for such events can have major consequences due to the minimum internal environmental conditions required for thermal comfort.

There are 3,884 active churches and cathedrals in Ireland [5] and ways must be found to conserve and preserve these buildings and their contents, whilst at the same time achieving a level of thermal comfort which allows them to remain used and relevant. Against this background and with the current volatility in the fossil fuel market, it is incumbent on the owners to ensure that these properties reduce their dependence on fossil fuels and reduce their carbon footprint. This paper will discuss one such cathedral which has shown potential for a renewable high efficiency heating system, located coincidentally in Cork, the virtual venue for this conference.

2. *METHODOLOGY*

Research was carried out into the 57 active cathedrals in Ireland rather than all of the 3,884 [5] churches because this was felt to be impractical and because what applied in cathedrals of similar size would also apply in churches. The stated difference between churches and cathedrals is the presence of the bishop's chair or cathedra, in a cathedral, not its size. Many churches are, in fact, larger than some cathedrals. It was important to visit and survey all of the 57 cathedrals first hand and this was undertaken over a two year period. During each visit, a comprehensive questionnaire was completed by the researcher, thereby obtaining a 100% response rate. The questionnaire was used to collect as much information about the cathedrals as possible, including data on age, construction type, denomination, usage, heating type as well as many other pieces of data. From this, 25 cathedrals were chosen to be monitored for at least a month during the heating season. The cathedrals

which were monitored represented some 44% of the 57 cathedrals, chosen as being a representative sample of religion, size, age, construction, location, heating type and other factors. Three of the 25 cathedrals were also monitored for a month when the heating was off, for control and baseline comparison purposes.

Data loggers were used internally and TinyTags externally to measure Temperature (T) and Relative Humidity (RH), where readings were taken every five minutes. Altogether this produced over 2.5 million pieces of data from which it was possible to calculate, amongst other trends, the heating and cooling rates in the various cathedrals. Five data loggers and one TinyTag were placed in each cathedral at a consistent height of some 2 metres, avoiding being near heat sources, windows and entrances, whenever possible. It was essential that the loggers were not seen or interfered with in any way.

St. Mary and St. Anne's cathedral in Cork was the focus of this study and as it has pillars separating the side aisles from the nave, it was possible to locate the loggers in areas where most people would sit, that is, in the nave. Ideally, in terms of occupant comfort, they would have been located at a height of some 2 meters above floor level, as this is the height within which people are located, but to avoid the loggers being removed they were consistently located at a height of some 3 metres without loss of relevance, given the absence of thermal layering over 1m. It is acknowledged that the location of the sensors was not always optimum but it was largely consistent. It was difficult and often impossible to locate them in optimum locations due to local restrictions on their placing and on the absolute necessity to cause no damage to the fabric of these protected and listed buildings. ANSI/ASHRAE Standard 55 (2010) [6] sets out the recommended heights at which readings should be taken but this was, for practical reasons, usually impossible to comply with.

The locations of the loggers in the Cork cathedral are shown in Figure 1.

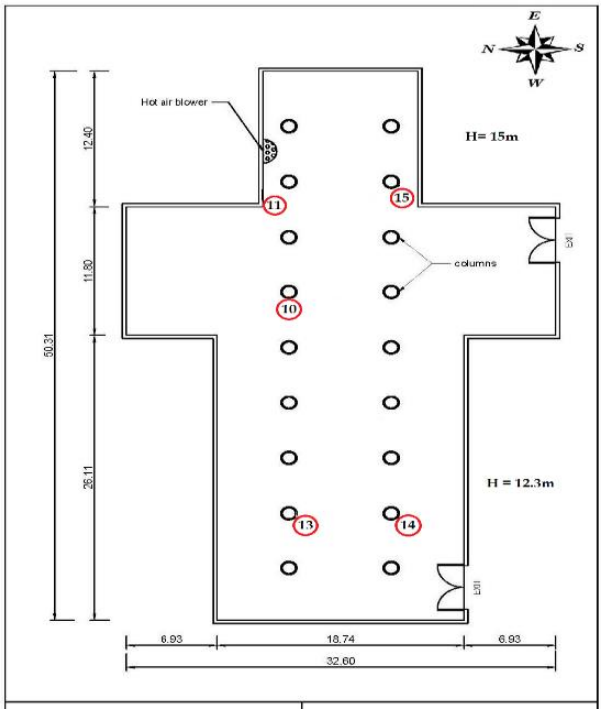

Figure 1. Floor plan with locations of loggers in St. Mary's Cathedral, Cork

3. HEATING SYSTEMS

The types of heating installed in the cathedrals in Ireland are shown in Figure 2. It can be observed that the Low Pressure Hot Water (LPHW) system is the type most commonly installed (36 out of 57 or 63%), although, whether they are the most efficient or the most appropriate, given the great changes of use which have taken place in recent years in these buildings, requires further research. Underfloor heating is also prevalent in both stand-alone form and with additional sources. The most modern cathedral in Ireland, namely St. Mel's in Longford, rebuilt in the last decade, uses this form of heating backed up by trench heaters. It is interesting that this form of heating has been chosen for a Roman Catholic cathedral in the 21st century given the way that St. Mel's, and indeed most Roman Catholic cathedrals, are used, that is, open all day and every day. The Roman Catholic cathedral in Armagh also has an underfloor heating system backed up with an LPHW system; however, they do not use the underfloor heating in order to save money. This completely alters the temperature regime in the cathedral and was almost certainly not what the consulting building services engineers planned when the system was installed. The philosophy of this design is to keep the underfloor system

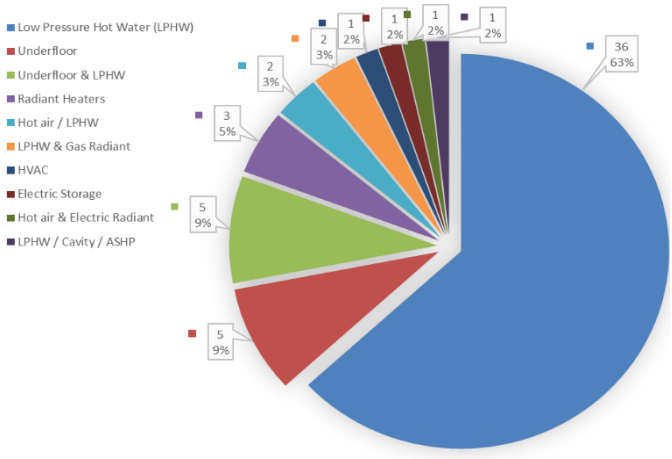

Figure 2. Breakdown of heating types in cathedrals in Ireland

running continuously to provide a low level of ambient heat and then to bring the LPHW system on line to raise the temperature for services and other events.

Only two cathedrals were found to be primarily heated with a hot air blower system; St. Mary and St. Anne's in Cork and St. Macartin's in Enniskillen. St. Columb's in Derry has a hot air blower but it supplements the primary LPHW system. There are major differences between St. Mary's and St. Macartin's, however, and direct comparisons would not be valid. For example, St. Mary's is approximately four times the size of St. Macartin's and St. Macartin's has a balcony which St. Mary's does not. This balcony would have a major influence

on air movement within the cathedral by trapping warm rising air beneath the balcony. The inlet and outlet of air in St. Macartin's is in the floor, as displayed in Figure 3.

Figure 3. Inlet and outlet grills for the hot air heating system in Enniskillen cathedral

In St. Mary and St. Anne's cathedral there is one grill which is high up on the wall, as displayed in Figure 4. Blower heating is supplemented by electric radiant heaters when required. Further research is required using computational fluid dynamics (CFD) to calculate the effect that these two contrasting heat sources would have on air movements within the respective cathedrals, but this is outside the scope of this research. CFD could also have been used to identify optimum locations for the sensors, but in practice the sensors had to be consistently put where they would not be seen or removed without being physically attached to the fabric of the buildings.

Figure 4. Hot air blower outlet (left) and electric radiant heaters (right) in St. Mary's Cathedral, Cork

4. *RESULTS*

Figure 5 shows the consolidated temperature readings for the internal loggers together with the external TinyTag readings, in St Mary's and St Anne's. These show that the air within the building heats up and cools down very quickly. This means that there is little time for the fabric of the building to absorb the heat and so fabric thermal mass and thermal lag over subsequent hours are not relevant [7]. However, the exfiltration rate of air from the buildings may also have been a factor as the temperature drops rapidly. The result is that little heat and

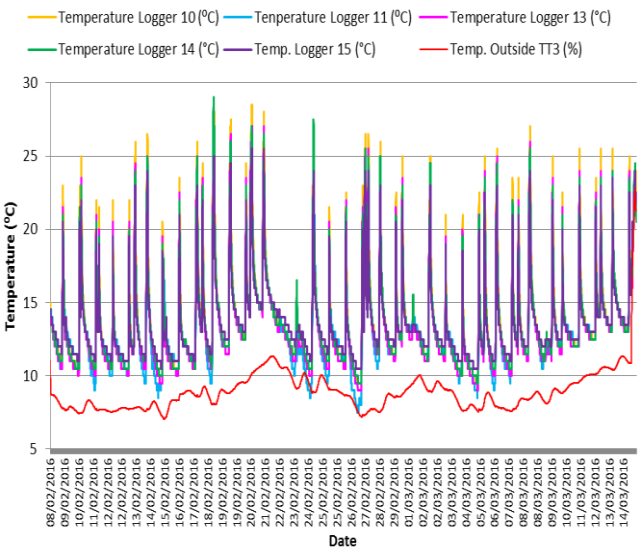

Figure 5. Temperature readings (indoors and outdoors) in St. Mary and St. Anne's Cathedral, Cork

energy is wasted by being released by the fabric in the days afterwards when the cathedral is not in use. However, it would be necessary to calculate the exfiltration rate of air from the building as well as the U values of the various components of the walls to establish just how much energy is being lost and such calculations were beyond the scope of this research.

With most cathedrals it is common for both the air within the buildings and the fabric of the buildings to warm up and then this heat slowly dissipates over a number of days, usually during low or zero occupancy. This effect is almost totally absent in St. Mary and St. Anne's cathedral. Not only does the graph show a sharp rise and fall of temperature but also that it reaches relatively high levels which, for a largely sedentary congregation, would provide more than adequate levels of thermal comfort.

Thermal comfort affects people both physiologically and psychologically with a great many variables relating to the people themselves, what they are wearing and doing in the building and their location within the building, as well as many other factors.

By analysing these trends over a shorter period, as for example shown in Figure 6, the sharp rises and falls of temperature are clearly demonstrated. The unusual average rate per hour increase in temperature in St. Mary's (typically over 10 °C per hour) is unique to that cathedral. The rates per hour increases in St. Mary and St. Anne's cathedral are shown in Figure 7. Most cathedrals with LPHW systems take many hours to warm up (with rates of less than 2 °C per hour) and even then most do not produce what is usually accepted as being an adequate level of thermal comfort.

By way of contrast, Figure 8 shows the rate of increase in St. Macartin's in Enniskillen, so the heating is on for much longer before events. This suggests that although St. Macartin's is much smaller, the oil fired boiler may be delivering much less hot air, or that the configuration of the inlet and outlet grills may not be ideal. It is also clear that there is considerable lag in the cooling down, in sharp contrast to that in St. Mary and St. Anne's shown in Figure 5.

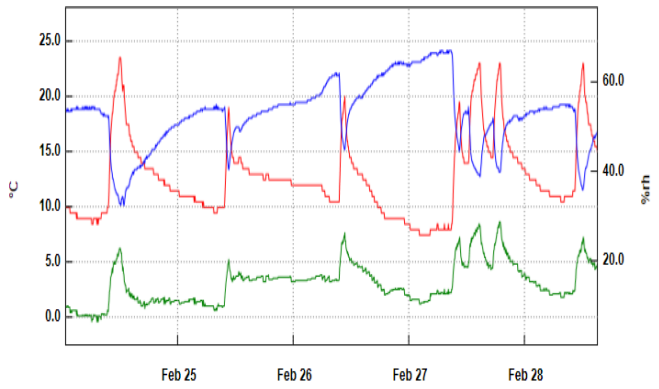

Figure 6. St. Mary and St. Anne's cathedral, Cork, Logger 11, from 24 to 29 February 2016 (T in red, RH in blue and external T in green)

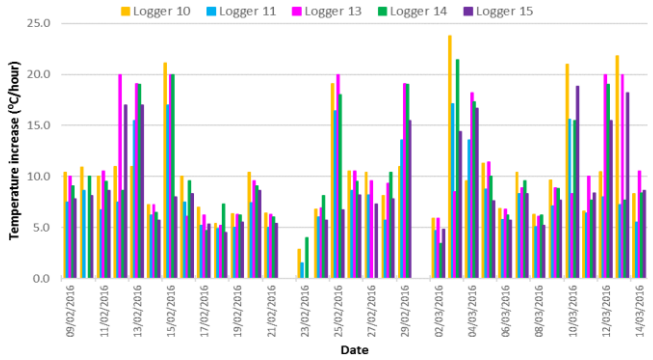

Figure 7. Rate of temperature increases per hour for the five loggers in St. Mary and St. Anne's cathedral, Cork

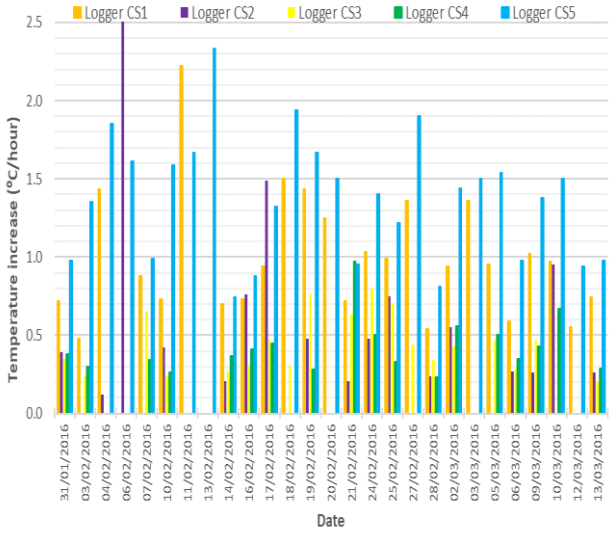

Figure 8. Rate of increase in temperature per hour for the inside loggers in Enniskillen

St. Mary and St. Anne's cathedral in Cork was the only one of the 25 cathedrals monitored which displayed the heating cooling profile described in this paper. Those cathedrals which had underfloor heating backed up with an LPHW system, such as the recently restored St. Mel's, as shown in Figure 9, displayed a more stable heating regime with a low level of background heat which was then boosted by an LPHW system. This, however, requires the underfloor heating to be running constantly, which is when this system operates most efficiently.

St. Macartin's also displays a typical heating profile for an LPHW heated cathedral with slower heating up and cooling down with much residual heat outside occupancy hours, as evidenced in Figure 10.

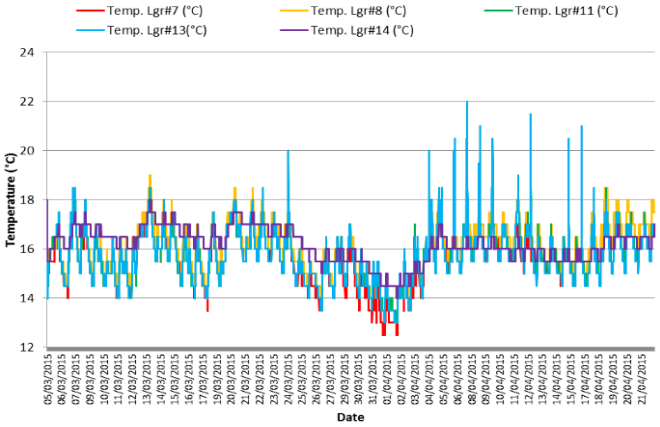

Figure 9. Temperature readings indoors of St. Mel's Cathedral, Longford

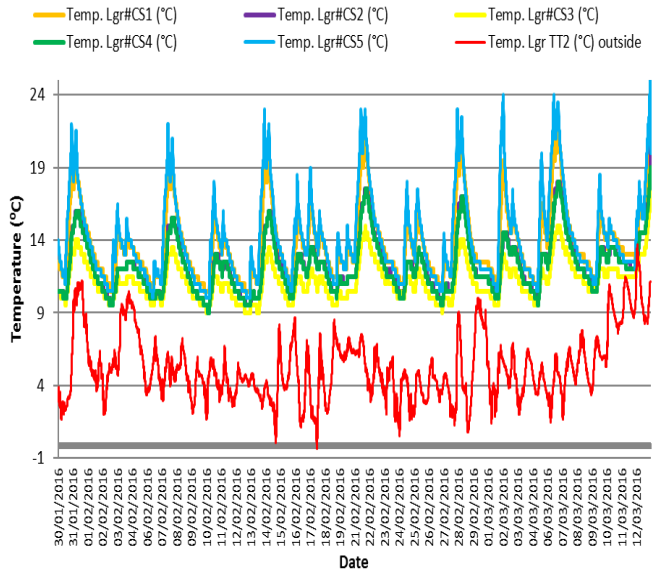

Figure 10. Temperature readings inside and outside for St. Macartan's Cathedral, Enniskillen

5. *DISCUSSION*

St. Mary and St. Anne's, like St. Mel's, is a Roman Catholic cathedral and a feature of that branch of Christianity is that their churches and cathedrals are open all day every day for personal devotions as well as organised services. Church of Ireland cathedrals, with some notable exceptions, tend to only open on Sundays and often for just one service. For that they usually heat the whole volume of air within the building rather than just the people within the building and often the fabric as well. Further research is needed in St. Mary and St. Anne's to determine the noise levels from the blowers, the exact cost of running the system and what contribution to the overall internal

thermal environment is provided separately by the hot air blower system and the small radiant heaters on the pillars. It would also be useful to carry out further research to determine if there are any renewable energy powered hot air blower systems in any churches or cathedrals anywhere with a similar climate to Ireland.

Heritage buildings such as churches and cathedrals are unique in many ways, having unusual usage patterns and thus one heating solution is most unlikely to be suitable for all. These buildings can be damaged in many ways [9] but particularly so by changes in temperature and RH over long periods. The contents are particularly susceptible to changes in temperature and RH as they contain artefacts comprising many hygroscopic materials such as paper, wood and leather. Therefore, the control of the temperature in cathedrals is not just for occupant comfort but for the preservation of its history. Hence, using a blower system for short periods which has the desired effect on occupant comfort during events, but has the least intrusion on the centuries-old environment of slow heating of the fabric may well be the best long term solution.

6. CONCLUSIONS

The system in St. Mary and St. Anne's, on the basis of the data gathered, seems to present a possible solution which provides a good level of thermal comfort for those using the building, whilst at the same time preserving and conserving the building and its contents by having the least intrusion on the natural interior environment. This paper has shown that because the rates of heating the air are much faster than for the more conventional heating systems (LPHW and underfloor), it has been shown that the fabric is not heated up during the short periods of application of heating and so there little waste of the heat normally stored in the fabric which is released in subsequent hours and days during very low occupancy.

Much further research is needed, however, to examine the respective contributions of the hot air heating system and the radiant heaters, each of which contribute to the overall level of thermal comfort within the building. These buildings are difficult to heat due to their pattern of usage, the permeability of the building envelope and their huge thermal inertia. Given that these buildings are either listed or protected and conservation and preservation of the buildings and their contents are important factors, it is difficult to establish the optimum sustainable system. The heating systems in St. Mary and St. Anne's cathedral may provide a solution to this complex matter.

REFERENCES

1. CAHILL, E. 2017. 'One of Dublin's largest Catholic churches to be demolished'. Irish Times, 3 February Available: http://www.irishtimes.com/newspaper/ireland. [Accessed 3 February 2017].
2. IRISH TIMES. 2016. 'Mass attendance in Dublin to drop by one-third by 2030'. The Irish Times. [online] Available: https://www.irishtimes.com/news/social-affairs/religion-and-beliefs/mass-attendance-in-dublin-to-drop-by-one-third-by-2030-1.2504351 [Accessed 4 April 2016].
3. faithsurvey.co.uk/irish-census.html. [Accessed 14 Mat 2020].
4 CODE OF CANON LAW. 2003. Available: http//www.vatican.va/archive/ENG1104/-INDEX.HTM. [Accessed 21 December 2016].
5. SHIELL, C., 2018. The thermo-hygrometric environment in cathedrals in Ireland. PhD thesis, Trinity College Dublin.
6. ANSI/ASHRAE Standard 55 (2004).
7. SCHELLEN, H.L. & VAN SCHIJNDEL, A.W.M. 2007. An Overview of Experimental and Simulation Work on Indoor Climate and Control in Historic Houses and Monumental Buildings. Contribution to the Experts Roundtable on Sustainable Climate Management Strategies, April 2007. Tenerife, Spain. The Getty Conservation Institute.
8. FEILDEN, B. M. 2003. Conservation of Historic Buildings, Oxford, Architectural Press. p. 96, 135, 136, 177.
9. CAMUFFO, D. 2014. Microclimate for Cultural Heritage, Amsterdam, Elsevier Science B.V. p. 4, 81, 89, 97, 100, 103, 226, 246, 331.