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# The power from above - A novel church heating system

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**Abstract.** This paper presents a novel heating system for churches based on a combination of an air-to-air heat pump for conservation and bench heating and overhead radiators for comfort heating. The heating system was implemented in a church in southern Sweden. Initial assessments showed that this type of heating system could provide an acceptable comfort for visitors with a significantly reduced energy and power demand. At the same time preservation conditions improved. A second assessment, ten years after the installation, showed that the performance was not as good expected. This was partly due to leaving the intended mode of operation, partly due to a need for technical adjustments. To meet future challenges the rural churches in Sweden need affordable heating solutions both for conservation and comfort. The proposed heating system is a step in that direction but further technical refinement as needed as well better user support to manage a new and more complex type of heating system.

**Key words:** church heating, comfort, conservation, radiation, conservation heating

## 1. Introduction

Most Swedish rural churches are used intermittently, often with less than one service per week. The challenge of heating such a church is to find affordable solutions that provide both comfort and a good indoor climate for preservation [1]

Comfort conditions for church visitors and staff are governed mainly by air and surface temperatures, air movements and clothing. In a conservation perspective, the indoor climate in a historic church is mainly determined by the relative humidity. High values of relative humidity increases the risk of biodegradation, such as mould [2]. Large variations in relative humidity (RH), often related to heating, can cause mechanical damage to hygroscopic materials [3].

The present paper presents a novel cost- and energy efficient solution for church heating that has been implemented and assessed in one Swedish church.

### 1.1. Intermittent heating

Intermittent heating means that the church is heated for comfort only for services [1]. In between services, the church is kept unheated or at a low temperature. The advantage of this heating strategy is that it provides an acceptable comfort with a relatively low energy demand. The disadvantage is that it requires much higher heating power as compared to continuous heating. In churches that are heated seldom, the (fixed) cost of heating power is often comparable to, or even or higher, than the (moving) energy cost.

When a church with massive walls is heated intermittently, most of the energy goes to heat up the walls. This means that conventional methods for calculating the heating load at steady state conditions are not applicable. Jakobsson [4] and Krischer [5] developed models for the calculation of heating-up loads and heating times in churches, eq. (1).

$$\Delta\theta_i = \frac{Pu\sqrt{\tau}}{A} + \frac{P}{\alpha A} \quad (1)$$

$\Delta\theta_v$	Wall temperature increase (°C)
$\Delta\theta_i$	Air temperature increase (°C)
$P$	Power input (W)
$\tau$	time (s)
$A$	Wall area (m <sup>2</sup> )
$\alpha$	Heat-transfer coefficient(W/m <sup>2</sup> °C)

The parameter  $u$  is defined by:

$$u = \sqrt{\frac{4}{\pi\lambda c\rho}} \quad (2)$$

$\lambda$	Heat conductivity (W/m°C)
$c$	Specific heat (J/kg°C)
$\rho$	Density (kg/m <sup>3</sup> )

Broström has shown how the theory can be used to determine heating power and heat up time for a given church [6] and Wessberg has further developed the theoretical model [7]. As can be seen in eq. (1), the air temperature will increase as a linear function of the square root of time during intermittent heating with constant heating power. This leads to a temperature curve that rises quickly in the beginning and then increases more and slowly, see figure 1. As a rule of thumb, the heating time increases proportional to the square of the required temperature increase.

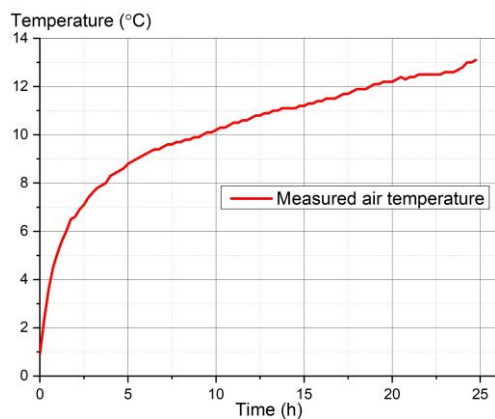


Figure 1. Measured temperature during intermittent heating of a sample church [7]

### 1.2. Radiative heating

As part of the EU project Friendly Heating Camuffo et al [8] developed a concept for radiative heating of churches in order to find a good compromise between the comfort of visitors and preservation. The basic idea is to heat visitors directly through radiation rather than heating the whole church. Different technical solutions and geometries for radiators installed in church benches were thoroughly tested in a church in northern Italy. In summary the outcome was that a properly designed radiative system can:

- Provide acceptable comfort for visitors with none or very little background heating
- Reduce the energy demand and power demand dramatically
- Provide a much better indoor climate for preservation as RH fluctuations related to heating are decreased.

### 1.3. Conservation heating

Heating used to control relative humidity for preservation purposes is called conservation heating [9]. The basic principle of conservation heating is to control the temperature in order to keep the relative humidity under a given limits. Hygrostats are used to control the heat input. The result is that the indoor temperature will be slightly higher than outdoor temperature throughout the year. There are some limitations to the use of conservation heating. In the winter, conservation heating may result in uncomfortably low temperatures, even below 0 °C. In the summer time, conservation heating may result in uncomfortably high temperatures. Broström and Leijonhufvud [10] showed the potential benefit of using air-to-air heat pumps for conservation heating with a stable heat load over the year and energy demand reduced typically by a factor of 3 as compared to direct electric heating.

## 2. A novel church heating system

This paper describes a novel heating concept for churches comprising the following parts:

- Hygrostatically controlled conservation heating with a heat pump
- Intermittent heating to raise the general indoor temperature to around 10° C.
- Radiative heating in benches and overhead to provide comfort during service

The hypothesis was that this, in comparison to a conventional heating system, would give

- Lower energy demand
- Lower power demand -> reduced fixed cost
- Acceptable comfort for visitor
- A better indoor climate for preservation

### 2.1. Pilot installation in Garda Church

Garda church is located on the south eastern part of Gotland. The church is constructed in limestone and was erected in the 12th century. The church is intermittently heated with a few services per month.



Figure 2: a) Garda church, b) the church benches with integrated heating foils in the back and radiators below the seat, c) the heat pump and overhead radiators) detail of overhead radiator

The new heating system in Garda church was installed in 2007 and had the following technical components:

- Electric radiators, were placed under seat of the benches, see figure 2 b.
- Electric heating foil was installed within the backs of the benches radiating mainly backwards, see figure 2 b.
- The wooden floor under the benches was insulated.
- Over-head radiators were installed in two tailor made chandeliers with a total heating power of 8 kW, see figures 2 c, d and 3.
- An air-to-air heat pump for conservation heating was integrated into back bench. The heat pump had a heating power of 6 kW and was hygrostatically controlled, see figure 2 c.
- Special heating arrangements were made for the priest and the organist.

The recommended operation procedure for the new heating system was:

1. Keep the heat pump on at all times for conservation heating. The hygrostat will activate the heat pump when RH goes above 65%.
2. Turn on all heat sources around six hours before service to increase background temperature to around 10 °C.
3. Go back to conservation heating after service.

### 3. Assessment

The assessment of the new heating was carried out with respect to comfort, conservation, cost, energy and power demand as well as usability.

#### 3.1. Comfort

The comfort was evaluated in 2009 and 2010 both through measurements and through test panels, involving both typical church visitors and students, that were invited to evaluate the perceived comfort according to an established method [11]. The comfort assessment showed that even with as low background temperature as 10 °C it was possible to get an acceptable comfort provided that the church visitors kept their outer clothes on.

#### 3.2. Conservation

Conservation heating ensures that the indoor climate is kept below mould risk level. There has been no problems with mould or smell after the installation. During one summer with very humid weather, the parish noted that nearby churches, without conservation heating, had problems with mould but not Garda church.

Variations in RH associated with intermittent heating may cause damages such as cracking and flaking of paint to polychrome wooden objects. With the implemented heating strategy, the general temperature during service in the church is raised to around 10°C rather than to a normal comfort temperature in the range of 18 – 22 °C. Thus the variations in RH are significantly reduced and kept within a safe range [12].

Another conservation problem in churches is soiling [13] where particles are deposited on the walls. Cleaning the walls is a very costly process especially if there are mural paintings. The rate of deposition depends on the difference between the air and wall temperatures as well as air movements. The implemented heating system reduces the rate of particle deposition as the air temperature is kept low and radiative heating causes much less air movements as compared to conventional systems with a high convective component.

#### 3.3. Energy and power demand

Hygrostatically controlled conservation heating provides mould risk control with a minimum of heating. The conventional practice was to heat the church to a constant set temperature, which most of the time results in heating either too little or too much in relation to mould risk. The COP of the heat pump varies over the year, on average it is around 3. As compared to direct electric heating, which would have been the option, the heat pump reduced both energy and power demand by 2/3.

By raising the general temperature in the church to only 10°C the energy demand is reduced much more than one would think. As an example, we can look at the time needed to raise the temperature from 5°C to either 10 or 20°C. The temperature rise differs by a factor of 3 between the two cases. According to the theoretical model (eq. 1 and figure 1) the heating time, and thus energy demand, would decrease by much more than a factor of 3.

The installed heating power of the radiative system is around 1/3 of what a conventional system would require. With the old heating system it would take around 24 hours, with much higher heating power, to heat the church to comfort temperatures. The new radiative system is turned on at full power only six hours before service.

In summary, the total installed heating power is around 30% of what would be required for conventional intermittent heating which gives a significant economic saving. Based on an estimated use



Figure 3: User test panel for comfort assessment

of the church once a month, the estimated saving for both conservation and comfort heating would be in the range of 60-70%.

#### *3.4. User feed back*

During the first year of operation the reports from the parish were mainly positive. In order to follow up on the long term outcome, interviews were carried out with representatives for the parish after ten years of use [14]. The second assessment showed that the heating system has not been used as intended. The radiators were turned on a long time before service to raise the background temperature to 16-17°C. During the service the overhead radiators were turned off because the heating power could not be regulated and some visitors found it too hot, especially when standing. In other parts of the church, away from the radiators, it was considered too cold.

An extra fan was needed to get a better distribution the warm air from heat pump. The noise from the heat pump and fan was disturbing to the point that it was turned off during services. The last years, the heat pump had been turned off between services and conservation was in fact discontinued.

#### **4. Conclusions**

The technical part of the assessment shows that the heating system presented in this paper has a potential to provide a good indoor climate, in terms of both comfort and conservation, at an energy and power demand that is much lower than conventional solutions. However, it is clear that the heating system has not performed as well as expected. The reason for this is mainly user related, but there is also a need for some technical refinement. During the planning and initiation phase of the new heating system there was consensus on the mode of operation as described above. The staff was thoroughly informed and early on there were several contacts in order to follow up on the performance of the new heating system. During the first year of operation, the feedback was mostly positive and minor problem were dealt with. Over a ten year period, the mode of operation changed gradually away from the original intention towards traditional heating practice. New staff came in and knowledge and know-how was lost. The first conclusion is that when introducing a new and more complex heating regime there is a need for annual follow up and retraining of the staff.

To high intensity from the overhead radiators was not perceived as a problem during the first assessment. The second assessment indicates that visitors have experienced discomfort from time to time. In another church with a similar heating system, the chandeliers holding the radiators could be manually raised or lowered in order to control heating intensity. This is not possible in Garda church, but a continuous power regulator is a simple and affordable solution.

From a conservation point of view, the heat pump worked well as long as it was in use. In hindsight two heat pumps would have given a better heat distribution in the church. The noise from the warm air fan also need attention.

The continued use of the rural medieval churches in Sweden has, more than anything else, contributed to their preservation up until today. To meet future challenges such as few visitors, lack of funding and climate change there is a need to find affordable solutions that can provide both a good indoor climate for conservation and acceptable, if not perfect, comfort for visitors and staff during services. The proposed heating system is a step in that direction. There is some need for technical refinement, but the main challenge is managing a new and more complex type of heating system.

#### **5. Acknowledgement**

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