The 9th International Conference "ENVIRONMENTAL ENGINEERING"
22–23 May 2014, Vilnius, Lithuania
SELECTED PAPERS
eISSN 2029-7092 / eISBN 978-609-457-640-9
Available online at *http://enviro.vgtu.lt*

Section: Sustainable Urban Development

Selection of Microclimate Systems in Brick Castles Considering the Requirements of Cultural Heritage

Giedrius Šiupšinskas, Inga Genytė, Jūratė Venckauskaitė, Jurgis Zagorskas

Vilnius Gediminas Technical University, Saulėtekio ave. 11, Vilnius 10223, Lithuania

Abstract

The application of brick cultural heritage buildings for public use very often reveals the confrontation of indoor microclimate requirements. Some requirements are applied only for the premises attended by the visiting people and other requirements – for the elements or protected exhibits of cultural heritage. Sufficient microclimate indicators can be provided by modern engineering systems, the selection of which is based on several criteria (microclimate requirements, energy efficiency, the amount of investment, operating costs, etc.). This work analyses several variants of microclimate systems for different building application, based on Panemune castle example and considering the possible difference in cultural heritage requirements. The calculated results are evaluated by multiple criteria evaluation.
The article was prepared according to the project material VAT-57/2012 "Innovative methods of regeneration of architectural heritage: castles of Panemune".

Keywords: brick heritage buildings; microclimate systems; HVAC systems.

Nomenclature

HVAC	heating ventilation and air conditioning
COP	coefficient of performance
x	non-dimensional (comparative) criteria of suitability, investments, operation and maintenance costs;
s	weight coefficients of suitability, investments, operation and maintenance costs
Subscripts	
max	alternative with maximal value
n	pending alternative
s	suitability
i	investment
om	operation and maintenance costs

1. Introduction and review

As it is not easy to combine man comfort, conservation needs and low costs, various solutions have been attempted, often disregarding conservation [1].

When the natural microclimate of a building is not comfortable for people (less frequently the problem is posed whether it is suitable for conservation too), heating ventilation and air conditioning (HVAC) systems are installed to obtain the desired comfort. Traditional systems are used, for example hot water radiators, fan coil convectors, radiant panels, humidifiers, following the everyday practice of keeping a temperature fluctuating around the selected level or switching on/off the system according to the activity periods with sudden peaks or drops in temperature (and, consequently, in relative humidity). All these systems are characterized by intermittent use and are located in spot areas, so that they continually generate microclimate perturbations. Fans tend to destroy thermal layering but generally worsen the situation, forcing air currents in the rooms [2].

Corresponding author: Giedrius Šiupšinskas. E-mail address: giedrius.siupsinskas@vgtu.lt
http://dx.doi.org/10.3846/enviro.2014.136

Requirements for microclimate in brick castles depend on building type, cultural heritage value and a number of elements in regenerated brick castle buildings. An appropriate HVAC system has to rapidly balance changes of indoor parameters from set point values, which means balancing the thermal loads which considerably affect microclimatic values, thermal load due to occupants in the exhibition areas, generally subject to rapid change and directly proportional to the degree of overcrowding, and thermal load related to outdoor air. As the literature analysis shows different types of HVAC system for the support of optimal indoor microclimate for different types of heritage buildings could be chosen: for churches [3–7], museums [1,8–10] and other types of heritage buildings [7, 11].

The main target of this article is the selection of optimal HVAC system for different types of regenerated brick castle premises. Five different building types where analysed (art studio/school, office building, hotel, museum, library).

Any changes regarding indoor climate, heating strategy or heating systems shall be evaluated to ensure that the objectives, with respect to conservation and comfort, have been met. Evaluation will include determining whether the desired climate conditions have been achieved, and whether any damage to cultural heritage objects that can be ascribed to the heating system has occurred. The extent and depth of the evaluation shall be determined in each case by an independent, qualified group of experts. Normally, the evaluation shall include indoor climate measurements and the response of objects and building over a period of at least one year, preferably more. Evaluation shall include asking the users of the building for their observations. Evaluation shall also include inspection of the fabric and the contents to determine any response to the changes. The first evaluation shall take place early on after installation, a second evaluation within 1 to 3 years after installation [12].

European Committee for standardization has special work group for standards preparation for Conservation of Cultural Heritage. There are several norms in which main factors of microclimate described [12].

In order to establish the historic indoor climate inside the building, measurements of temperature and RH shall be taken over a period of at least a year, and any records consulted for earlier years. For reference, similar measurements shall be made for external conditions over the same period and/or meteorological records consulted.

Relative humidity (RH) is generally the most critical parameter from a conservation point of view and therefore shall be kept at a defined level and as stable as possible. RH depends on both the temperature and the moisture content of the air. Attention shall be paid to the fact that in the immediate vicinity of surfaces RH is determined by the surface temperature which may be different from the general room temperature. Determining a target range for the place of worship means taking into consideration the issues listed below and adjusting a number of ranges into a common range. Experts shall be consulted when defining the final target range [12].

2. Methodology

In this article three main criteria investigated are: suitability, investments, operation and maintenance costs. In order to find the best solution, a concept of multicriteria analysis is implemented for estimation of the miscellaneous alternative selection [13]. The non-dimensional values of investigated criteria are recalculated in accordance with equation:

$$x = 1 - \frac{X_{max} - X_n}{X_{max}}, \tag{1}$$

The optimal (factor E) result is calculated on the assumption that all criteria are equally important:

$$E = x_s \cdot s_s + x_i \cdot s_i + x_{om} \cdot s_{om} \to max. \tag{2}$$

3. Research object

Vytėnų castle is located in Panemunė Regional Park territory near Jurbarkas town. Its functions were defensive, residential, and administrative. Archaeological research has revealed that the materials used for subsequent Vytėnų castle construction was from castle named Christmemel that used to stand in the same place [14]. In the science project “Innovative methods of regeneration of architectural heritage: castles of Panemunė”, since 2012 funded by the Research Council of Lithuania, researchers from Vilnius Gediminas Technical University revealed features of evolution of Vytėnų and Panemunė castles’ plans. Based on archival material and nature studies castle layouts of several periods were restored (Fig. 1 shows the scheme of Vytėnų castle ground floor in the middle of XVII).

Now one part of Vytėnų castle is regenerated, new ground floor heating system with natural and mechanic ventilation system is installed. The main heat source for heating and ventilation is (water – water) heat pumps. Other part of the building has no heating and ventilation. In this article the part of non-regenerated building is analysed. The total analysed area covers 250 m^2. The main facades are presented in Figure 1.

Fig. 1. Vytėnų castle ground floor middle of XVII c and facades of analysed part of the building. (according to the result of project "Innovative methods of regeneration of architectural heritage: castles of Panemunė")

4. Analysed variants and results

In this article several possible variants of regeneration where investigated. The example of Penemunė castles shows that red brick heritage buildings could be used for different purposes. Five possible building type scenarios (art studio/school; office building, hotel, museum and library) where analysed. In table 1 heating, ventilation and air conditioning systems are presented and rated from technical point of view.

4.1. Heating systems

Radiator heating. A radiator is a heating element where heat is transmitted to the surroundings mainly through radiation. Radiators are heated with hot water or electricity. They have lower surface temperatures than IR heaters and generally require larger heat emitting surface areas.

Most radiators will cause convective movement of warm air and deposition of particles on walls and ceiling. Salt crystallisation may be another adverse effect. Radiators should not be placed near sensitive surfaces or objects in order to not to cause damaging microclimates. Radiators are usually mounted on the wall or on the floor and their overall visual impact is strong, since the total radiator required is generally large in relation to the size of the building. Pipes and electric cables generally require passage through walls and floors and may cause considerable damage [15].

Radiant (floor) heating. Floor heating (also referred to as under-floor heating) uses the floor surface itself as a heat emitter. Heat may be supplied either by embedded electric heating elements or by the circulation of water as part of a hydronic system, involving appropriately spaced pipes positioned beneath the floor surface. The pipes may be embedded within the screed of a solid floor or laid in a carefully controlled configuration beneath a suspended floor surface.

The heat emission characteristics of floor heating differ considerably from those of radiator heating. Floor surface temperature is critical to comfort, as well as to heat output. The optimum floor temperature range for comfort lies between 21 °C and 28 °C depending on surface material.

The design surface temperature is controlled by the spacing between pipes and the flow water temperature. It is also affected by floor construction, floor covering and the depth of the pipes beneath the floor surface; detailed design procedures are given by system manufacturers [15].

Deposition of particles on surfaces is generally increased by air movement. A floor heating system may be inconspicuous, but the invasive impact on the floor is considerable. This system shall not be installed in the case of historic or artistic floors, in the presence of buried tombs or archaeological remains.

Underfloor heating is generally not well suited for intermittent heating due to the thermal inertia of the system. Wooden pews or other objects covering the floor may reduce the heating effect [12].

Radiant (wall) heating. This method is based on providing continuous heating to the building envelope in masonry structures. Normally this is done with heating tubes installed in the plaster on the inside of outer walls. A less intrusive measure that works on the same principle is to install pipes on the surface of the walls. This method may provide limited thermal comfort depending on the amount of heat provided. Heating the inner surfaces of the room, will lead to better comfort as compared to convective heating at the same air temperature.

The invasive impact is considerable if the heating elements are installed inside the wall. This system shall not be installed in the case of historic or artistic walls, especially in the presence of mural paintings. This method is generally not well suited for intermittent heating due to the thermal inertia of the system. This system will heat the most critical points in the construction (corners) where otherwise often condensation may occur. Thereby it helps to prevent mold or algae growth. In the case of rising damp, the system may result in damage due to salt efflorescence heating the walls helps to reduce draughts and particle deposition [15].

Central air heating system (all air system). In a warm-air heating system, air heated to a pre-selected temperature is added to the building through convection, i.e. through circulation of warm air. Air from the building is filtered, heated and transported back into the building through a warm-air duct system. Outside air can also be added to the circulating air to improve air quality and moderate temperatures. The warm air can be generated by any kind of conventional heat source.

Warm-air heating can be used for all heating strategies. By definition, warm-air systems cause air movements. The systems shall be properly designed and tuned in order to minimise air movement in the building and to provide an even temperature distribution throughout the space. The distribution of heat depends to a large extent on the arrangement and number of warm-air vents/convectors, on the air outlet temperature and speed as well the internal topography of building.

In buildings with no air duct system, installing a new central warm-air heating can be highly invasive. However, if there is an existing duct system, it may be possible to upgrade it with an acceptable intervention [15].

Fan coil system (air–water system). These systems heat or cool air in the heated space using coils fed by heated or chilled water, which is distributed by conventional hydronic circuits. A fan coil is a packaged assembly comprising coils(s), condensate tray, circulating fan and filter. The fan recirculates air from the space continuously through the coil(s) either directly or via the void in which the fan coil is located.

- Two-pipe non-changeover systems: a single coil is supplied with chilled water only via a water circuit. Heating is normally provided either by a separate perimeter system or by electric heaters in the fan coil units.
- Four pipe systems: separate heating and cooling coils are incorporated, fed by heating and chilled water circuits respectively.

The fan recirculates air from the space continuously through the coil(s) either directly or via the void in which the fan coil is located. Ventilation is usually provided by a separate central air handling unit (AHU) or it can be drawn through an outside wall by the room unit itself.

Benefits provided by fan coil units include: significantly smaller ventilation plant and distribution ductwork than all-air systems; individual zone control of temperature, if suitable controls fitted; high cooling capacity; flexibility to accept future changes in load and layout.

Fan coils are best suited to applications with intermittent medium to high sensible loads and where close humidity control is not required, e.g. offices, hotels, restaurants etc. [15].

4.2. Air conditioning systems

Direct expansion systems (split, multi–split, super multi–split, VRF). The term 'direct expansion' describes an evaporator in which all the refrigerant supplied completely evaporates producing superheated vapour at the exit. This is in contrast to a flooded evaporator in which only partial evaporation takes place, producing saturated vapour at the exit. The term "direct expansion" (DX) covers single room units, multisplit, ducted and variable refrigerant flow (VRF) systems. Direct expansion cooling may also be used for close control applications.

In general direct (DX) systems are thermodynamically more efficient (i.e. they have a higher COP) than indirect systems because they directly cool the substance or space being cooled without the use of an intermediate coolant and additional heat exchangers. However, in practice other factors such as the surface area of evaporators and condensers, compressor and fan efficiencies can significantly affect efficiency and large well engineered chillers can be more efficient than some direct systems.

Chilled ceiling (air–water system) systems provide cooling almost entirely by convective heat transfer. An alternative strategy is to provide cooling by a combination of radiation and convection using, for, example, chilled ceilings. Such systems cool objects within commonly known as radiant cooling systems, only 50–60% (maximum) of the heat is transferred by radiation.

Chilled ceilings use chilled or cooled water as the cooling medium, normally between 13 °C and 18 °C. There are many different types of chilled ceiling devices, but essentially they fall into three main categories.

These are: radiant ceiling panels: in which the cooling capacity is distributed across the ceiling using serpentine chilled water pipework. Passive chilled beams: which have a more open structure and a heavier reliance on natural convective air movement; cooling is concentrated in finned coils similar to conventional heat exchangers.

Active chilled beams: which are similar to the above but with the air movement through the beam being mechanically assisted. With active chilled beams ventilation is an integral part of the beam, being induced by the central air handling plant. However with passive chilled beams and panels, ventilation has to be introduced separately, either by mixed flow or more normally by displacement ventilation. Chilled beams can either be capped or uncapped, i.e. unconnected to the ceiling void or connected to the ceiling void. They can also be flush mounted to the ceiling or hung, exposed, from the ceiling although care is needed to ensure that the required performance is achieved at the selected distance between the beam and the ceiling. Chilled ceilings can be applied to both new-build and refurbishment projects. However, they are not suitable for situations where a close-controlled environment is required [15].

In order to select optimal HVAC system for different types of the analysed buildings expert evaluation was chosen. Three main factors where investigated: suitability (technical possibility to install HVAC systems into the analysed heritage brick building), investments, operation and maintenance costs. Heating, ventilation and air conditioning systems' expert evaluation is presented in Table 1.

Table 1. Heating ventilation and air conditioning systems' expert evaluation

	Arts studio/school	Office building	Hotel	Museum	Library	Investments	Maintenance
Heating system							
Radiator heating	2	2	2	1	1	4	4
Radiant (floor) heating	4	4	3	4	3	1	3
Radiant (ceiling) heating panels	2	3	2	3	2	1	3
Radiant (wall) heating	2	2	1	1	1	1	3
Central air heating system (all air system)	2	4	1	2	3	2	1
Fan coil system with fresh air supply (air–water system)	2	3	4	1	1	3	2
Heating ceiling (capillary heating)	2	3	2	3	2	1	3
Ventilation system							
Natural supply and exhaust system	2	1	2	1	1	3	3
Mechanical supply and exhaust system	3	4	4	4	4	2	2
Air conditioning systems							
Direct expansion systems (split, multi–split, super multi–split, VRF)	3	3	4	1	1	1	1
Central air system (all air system)	3	3	1	4	4	3	3
Fan coil system (air–water system)	2	4	4	1	1	4	2
Active chilled beams (air–water system)	2	3	2	1	1	2	3
Passive chilled beams (cooling panels) (air–water system)	3	3	3	3	3	2	4
Chilled ceiling (air–water system)	3	3	3	3	3	2	3

In Table 1 values represent non dimensional form of building systems. In suitability scale:
1 – not suitable (for technical or heritage requirement reasons);
2 – system integration technically possible, but not recommended;
3 – good solution from technical and heritage point of view
4 – the best solution from technical and heritage point of view.

The same gradation was used for the evaluation of investments, operation and maintenance:
1 – the highest investments and operation and maintenance costs;
4 – the lowest investments and operation and maintenance costs.

For the calculation of factor E these weighted coefficients where used: 0,5 for suitability; 0,25 – investments and 0,25 operation and maintenance costs. The highest weight was given for suitability because it had the highest influence on the result.

The final calculation results are presented in Table 2.

Table 2. Results of multicriterion evaluation

	Arts studio/school	Office building	Hotel	Museum	Library
Heating system					
Radiator heating	**0.75**	**0.75**	0.75	0.63	**0.63**
Radiant (floor) heating	**0.75**	**0.75**	0.63	**0.75**	**0.63**
Radiant (ceiling) heating panels	0.50	0.63	0.50	0.63	0.50
Radiant (wall) heating	0.50	0.50	0.38	0.38	0.38
Central air heating system (all air system)	0.44	0.69	0.31	0.44	0.56
Fan coil system with fresh air supply (air–water system)	0.56	0.69	**0.81**	0.44	0.44
Heating ceiling (capillary heating)	0.50	0.63	0.50	0.63	0.50
Ventilation system					
Natural supply and exhaust system	**0.63**	0.50	0.63	0.50	0.50
Mechanical supply and exhaust system	**0.63**	**0.75**	**0.75**	**0.75**	**0.75**

Continued Table 2

	Arts studio/school	Office building	Hotel	Museum	Library
Air conditioning systems					
Direct expansion systems (split, multi–split, super multi–split, VRF)	0.50	0.50	0.63	0.25	0.25
Central air system (all air system)	0.75	0.75	0.50	**0.88**	**0.88**
Fan coil system (air–water system)	0.63	**0.88**	**0.88**	0.50	0.50
Active chilled beams (air–water system)	0.56	0.69	0.56	0.44	0.44
Passive chilled beams (cooling panels) (air–water system)	**0.75**	0.75	0.75	0.75	0.75
Chilled ceiling (air–water system)	0.69	0.69	0.69	0.69	0.69

According to Table 2 the best variant for different types of heritage brick buildings represents the highest value of multicriterion factor E. In some cases there are several possibilities of the best HVAC systems integration.

5. Conclusions

- Analysis showed that in brick castle heritage buildings heating, ventilation and air conditioning systems integration depend on different factors: suitability, investments, operation and maintenance costs. That is why multictirion evaluation is a good choice.
- The investigated regeneration possibilities of Vytėnų castle heating, ventilation and air conditioning systems showed that in case of art studio/school the best solution for heating system would be radiator or radiant (floor heating), ventilation equally natural or mechanical and air conditioning system central air system (all air system) or passive chilled beams (cooling panels) (air–water system)
- The same results for heating are found in office building and library scenarios. In the case of museum radiant (floor) heating and hotel – fan coil system with fresh air supply (air–water system) where the best.

References

[1] Bellia, L.; Capozzoli, A.; Mazzei, P.; Minichiello, F. 2007. A comparison of HVAC systems for artwork conservation, *International Journal of Refrigeration* 30(8): 1439–1451. http://dx.doi.org/10.1016/j.ijrefrig.2007.03.005
[2] Camuffo, D. 2014. *Microclimate for Cultural Heritage. Conservation, Restoration, and Maintenance of Indoor and Outdoor Monuments*. 2nd ed. Elsevier Science. 526 p. ISBN 9780444632982.
[3] Bencs, L.; Spolnik, Z.; Limpens-Neilen, D.; Schellen, H. L.; Jütte, B. A. H. G.;Van Grieken, R. 2007. Comparison of hot-air and low-radiant pew heating systems on the distribution and transport of gaseous air pollutants in the mountain church of Rocca Pietore from artwork conservation points of view, *Journal of Cultural Heritage* 8(3): 264–271. http://dx.doi.org/10.1016/j.culher.2007.05.001
[4] Camuffo, D.; Pagan, E.; Rissanen, S.; Bratasz, Ł.; Kozłowski, R.; Camuffo, M.; della Valle, A. 2010. An advanced church heating system favourable to artworks: A contribution to European standardisation, *Journal of Cultural Heritage* 11(2): 205–219. http://dx.doi.org/10.1016/j.culher.2009.02.008
[5] Makrodimitri, M.; Papavasileiou, S.; Campbell, J.W.P.; Steemers, K. 2011. Heating historic structures. A review of heating systems in historic church buildings and implications related to conservation and comfort. The case of four historic churches in Cambridge, in *Proc. of Energy Management in Cultural Heritage conference 2011.*
[6] Schoffelen, M. E. A.; Schellen, H. L. 2004. Thermal performance of a local bench heating system for churches, in *Proc. 9th International Conference on Air Distribution in Rooms: 5–8 September 2004, University of Coimbra, Portugal. Silva, Manuel C. Gameiro da, ed. 2004.*
[7] Spolnik, Z.; Worobiec, A.; Samek, L.; Bencs, L.; Belikov, K.; Van Grieken, R. 2007. Influence of different types of heating systems on particulate air pollutant deposition: The case of churches situated in a cold climate, *Journal of Cultural Heritage* 8(1): 7–12. http://dx.doi.org/10.1016/j.culher.2006.09.003
[8] Camuffo, D.; Grieken, R. V.; Busse, H.; Sturaro, G.; Valentino, A.; Bernardi, A.; Blades, N.; Shooter, D.; Gysels, K.; Deutsch, F.; Wieser, M.; Kim, O.; Ulrych, U. 2001. Environmental monitoring in four European museums, *Atmospheric Environment* 35(1): 127–140. http://dx.doi.org/10.1016/S1352-2310(01)00088-7
[9] La Gennusa, M.; Lascari, G.; Rizzo, G.; Scaccianoce, G. 2008. Conflicting needs of the thermal indoor environment of museums: In search of a practical compromise, *Journal of Cultural Heritage* 9(2): 125–134. http://dx.doi.org/10.1016/j.culher.2007.08.003
[10] Padfield, T.; Borchersen, K. 2007. *Museum Microclimates.* Contributions to the Copenhagen conference, 19–23 November 2007, The National Museum of Denmark, Copenhagen, 2007.
[11] Camuffo, D.; Pagan, E.; Bernardi, A.; Becherini, F. 2004. The impact of heating, lighting and people in re-using historical buildings: a case study, *Journal of Cultural Heritage* 5(4): 409–416. http://dx.doi.org/10.1016/j.culher.2004.01.005
[12] Standart BS EN 15759-1:2011.Conservation of cultural property. Indoor climate Guidelines for heating churches, chapels and other places of worship. 2011.
[13] Rogoža, A.; Čiuprinskas, K.; Šiupšinskas, G. 2006. The optimisation of energy systems by using 3e factor: the case studies, *Journal of Civil Engineering and Management* 12(1): 63–68.
[14] Žalnierius, A. 2005. *Panemunės dvaro rūmų archeologiniai tyrinėjimai* [The archaeological investigations of the panemunė manor house]. Vilnius, p.133
[15] *Heating, Ventilating, Air Conditioning and Refrigeration: CIBSE Guide B. 2005*. *Chartered Institution of Building Services Engineers*, p. 369