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Design of a smart system for indoor climate control in historic underground built environment

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Abstract

The application of sensors-actuators networks in Building Heritage can lead to significant improvement in indoor climate control, with the aim to both reduce energy consumption, and improve conditions for occupants and hosted Heritage. This study proposes the preliminary design of a smart indoor climate control system, based on low-impact application criteria, which can be applied to visited underground built environment. The system is based on the balance of hygrothermal loads. Sensors and actuators requirements are defined, and control algorithm are based on the comparison between real-time monitored and "natural" temperature and hygrometric values (for stationary and transitory conditions).

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Keywords: smart control systems; underground built environment; indoor climate in Building Heritage; heritage preservation; hygrothermal loads

1. Introduction

The development in low-cost and intelligent sensors and actuators networks for indoor environment applications [1–3] allows to design systems for determining main environmental parameters (in real-time) and performing corrective action aimed at restoring optimum conditions. Similar systems could improve energy consumption and

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occupants' comfort, because they are automatically activated as soon as unsuitable indoor conditions are detected. These devices can be useful to balance the variations of the main indoor environment parameters, and especially the ones connected with hygrothermal loads and Indoor Air Quality (IAQ) [4,5].

Building Heritage are significant scenarios because of the necessity to develop sustainable retrofit actions and also facilitate the preventive conservation of hosted goods and chattels [6–9]. This study proposes the first steps in the development of a smart system for indoor climate control based on a real-time sensor-actuator network applied to a significant Building Heritage scenario (hypogeum). To this end, according to the literature review on driving factors for indoor climate control in such environment (Section 2), methods and requirements of the system are defined, by focusing on the main aspects of the application to a significant case study (Section 3). Then, the results section (Section 4) describes the proposed system and the suggested control algorithms, and a discussion on the system capabilities and on the next works steps is offered (Section 5).

2. Indoor climate control in historic built environments: main issues

Building Heritage are characterized by critical conditions due to their current use, such as:

- adaptations into new purposes (Building Heritage reuse [8]), with the need to adapt indoor parameters to current standards, including the ones for users' comfort levels [10]);
- massive and/or long-lasting tourists' presences in cultural spaces, that lead to environmental stresses due to the human presence during the time (e.g.: museum, galleries, other cultural sites) [11,12].

Similar buildings are generally natural ventilated [6,11], while existing building components (e.g.: walls layers, windows characteristics) and technological systems (e.g.: heating/cooling systems) are respectively affected by degradation and obsolescence, as well as there are generally not adequate to current building standards [13]. Maintenance interventions, modifications (aimed at adapting building to standards) and elements additions could lead to significant problems while respecting the original building features [14].

Beside the common problems for occupants related to comfort levels, well-being issues and hygienical/health aspects, critical indoor climate parameters could affect the conservation state of built environment elements, such as paintings, decorations and building surfaces [6,15]. The built environment could be affected by the occurrence of favourable conditions for moulds, fungi, algae, and other bacteria growth, as well as for cyclical stresses to materials due to hygrothermal loads variations during time [16,17]. The development and the application of control systems based on real-time monitoring solutions could allow to maintain indoor climate in a certain range (and ratio) during the time in order to guarantee proper conditions [7,11].

These control systems are "smart" because [4,11,18]: 1) they operate "*when*" effectively needed; 2) they are of use for both *preventive conservation strategies* and *internal environmental quality enhancement*; 3) additional *energy consumption benefits* could be reached limiting their operation during the time. Nevertheless, their impact should minimized on the building [19,20], mainly by acting on existing components, such as windows, shades and other technical systems (e.g.: fan coil) [11]. In the number of indoor climate parameters, temperature and humidity (in particular, relative humidity *RH* [%]) seems to be key factors for both occupants' comfort [5] and phenomena of surfaces degradation [6,11,21]. Hence, they should be monitored (and then controlled) during the time, in different significant scenario positions (i.e.: near to Heritage elements with artistic and cultural values). Although many guidelines for monitoring rules have been recently provided [20,22–24], the development of control systems based on a sensor-actuators networks in Building Heritage is still limited (and main based on warning and alert messages) [18,25,26] and monitoring systems are generally used to control the effectiveness of indoor climate technical installations [6,11].

From this point of view, underground man-made structures (hypogeum) represent ones of the most interesting case study [12,27]. In such spaces, many studies evidence the presence of possible biodeterioration agents for the built environment surfaces [15]. As shown for algae and other biological attack in building heritage, controlling the level of moisture (as a result of relative humidity on the wall) works as biocide agent. In fact, the availability of water in the material is a key factor for algae and microorganisms' growth. The water available to the microorganisms often depends on the material water activity, which is equivalent to the *RH* of the surface. Although