Building and Environment 86 (2015) 203–210

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Indoor air temperature monitoring: A method lending support to management and design tested on a wine-aging room

Alberto Barbaresi*, Daniele Torreggiani, Stefano Benni, Patrizia Tassinari

Department of Agricultural Sciences, University of Bologna, Italy

ARTICLE INFO

Article history:
Received 1 November 2014
Received in revised form
21 December 2014
Accepted 6 January 2015
Available online 13 January 2015

Keywords:
Air temperature monitoring
Thermal zone
Building design
Building energy modeling
Wine cellar

ABSTRACT

Indoor air temperature monitoring is a basic activity giving useful information in many fields such as human thermal comfort, food preservation conditions and energy simulations. The collected data can help the room management and, their elaborations, can improve energy-efficient building design. The survey equipment installation in an indoor space – sensor number and positions, record frequency – is a delicate procedure depending on several conditions related to the specific room. Nevertheless specific installation procedures are nor defined or codified in the scientific literature. This study aims at the definition of a temperature survey method, both accurate and cost-effective, able to quantify and maximize precision and accuracy of the temperature monitoring in indoor spaces, through an experimental temperature test carried out on a wine-aging room of an Italian wine farm. The method allows to identify homogeneous temperature zones, the number of sensors to be installed and the proper data recording frequency, based on the specific needs of the process under study. This method is experimentally validated by means of a test carried out on a wine-aging room.

1. Introduction

The indoor air temperature monitoring is an important procedure providing data about room temperature trends, in particular, in building industry, data can be used to assess the human thermal comfort [1], building management [2] or food preservation conditions when temperature trends are crucial [3].

As well known, indoor air temperature can be different from point to point within a room at a given instant. Nevertheless, in several monitoring campaigns, one single sensor is placed [4], usually in the center of the room, meaning the temperature has been considered uniform or, more precisely, the temperature differences have been considered negligible. This entails the concept of thermal uniformity should be defined prior to the monitoring process, according to the precision required by the research. A literature review shows that basically temperature can be assumed to be uniform when the room has limited dimensions, a regular shape or when boundary conditions guarantee thermal stability (i.e. apartments [5] or underground rooms [6]).

On the other side, in large indoor spaces (such as warehouses [7] or theaters, churches [8]) the temperature differences cannot be neglected and more than one sensor should be placed. The literature review shows the main adopted solution consisted of positioning the sensors on a virtual grid vertexes. This sensor positioning guarantees a precise survey, but the presence of the sensors can obstruct the normal activities in the room and a high sensor number can make the survey expensive and data elaboration more complex. The description of the choice related to sensor number and position and recording frequency, is often omitted since based on case-specific empirical approaches. Moreover a codified and standard methodology cannot be found in the scientific literature. However, this aspect plays a crucial role in the efficacy and cost-effectiveness of the management and design processes.

The main idea of this research is the identification of zones at uniform air temperature (called "thermal zones") within the room. A thermal zone identification in fact (made before the monitoring starts), can drive to the choice of definitive number and position of the sensors, helping to avoid errors (i.e. temperature uniformity assessment) and apparatus overestimations (i.e. too many sensors rise costs, data to elaborate and create obstacles to room normal activity). Under this perspective, the thermal zones identification can lead to a temperature monitoring method both accurate and cost-effective.

* Corresponding author. Viale G. Fanin 48, 40127 Bologna, Italy. Tel.: +39 051 209 6194.
E-mail address: alberto.barbaresi@unibo.it (A. Barbaresi).

http://dx.doi.org/10.1016/j.buildenv.2015.01.005

Nomenclature

n	number of sensors
m	number of records
IRV	identity reference value
ARV	acceptability reference value
Arrays	
t	temperature arrays
d	arrays of difference between any couple of **t** arrays
a	average temperature array
e	arrays of difference between **a** array and **t** arrays
v	differences between temperatures collected by the chosen loggers
Matrices	
M	mean of **e** arrays
S	standard deviation of **e** arrays
Z	sum of mean and standard deviation of **e** arrays
Subscripts	
i	generic time step
j and k	generic data-logger

Temperature monitoring is an important tool for building energy simulations as well, both for the input phase [9] and validation and calibration phases [10]. In several energy programs [11,12] the modeling phase entails the subdivision of the building into thermal zones: portion of volume in which the air temperature can be considered uniform. Usually rooms and thermal zones coincide but in some cases (rooms with particular shape, dimensions, boundary conditions), one room can be subdivided in more than one thermal zone. Therefore, a temperature monitoring based on thermal zone subdivision, as proposed in this paper, eases the modeling phase when calibration is required.

Finally a precise thermal monitoring can lend support both to management [13] and design phases, allowing fast intervention when temperature reach values considered hazardous for the product quality (i.e. wine) and providing important data for the energy simulations since monitored data are considered a valid source in calibrating building energy models [14].

Thus, this study aims at the definition of a temperature monitoring method, both accurate and cost-effective, able to quantify and maximize precision and accuracy of the temperature monitoring in indoor spaces, through an experimental temperature test carried out on a wine-aging room in an Italian wine farm. The method is developed setting the proper precision and identifying homogeneous zones in terms of temperature within the room, the number and position of sensors to be installed and the proper monitoring frequency.

2. Materials and methods

The research has been carried out on a wine-aging room of an Italian wine-growing and producing farm. In 2012, a collaboration was established between the research group and the farm. The collaboration has aimed at the functional optimization and energy efficiency of the wine-making process [15] based on data surveys [16], experimental calibrations [10] and computer simulations [17]. The farm is located in the eastern part of the Emilia Romagna Region where viticulture and fruit farming are widespread and consolidated activities. The methodology and the survey equipment have been defined, tuned and validated through the following protocol:

- Definition of the target precision;
- Proposed methodology:
  - Definition and identification of the thermal zones and their temperature;
  - Definition of the number and position of the sensors for the definitive monitoring;
  - Record frequency definition.
- Case-study application.
- Experimental validation.

2.1. Definition of the target precision

The precision has been set according to the specific aim, then, based on such value, sensor requirements in terms of accuracy and resolution have been identified and, consequently, the temperature threshold for the thermal homogeneity has been defined. For this study, the temperature reference value comes from the temperature tolerance needed in wine-aging process.

A comparative analysis, based on the scientific literature, shows results dependent upon many factors such as site, wine variety and quality. Troost [18] suggests two different intervals: one for white wines (9 °C–12 °C) and one for red wines (12 °C–15 °C). Bondiac [19] recommends a constant temperature between 10 °C and 12 °C, Marescalchi [20] temperatures between 15 °C and 20 °C in the first year and between 4 °C and 12 °C for the following years. The SEPSA [21] remarks the importance of a constant temperature between 8 °C and 14 °C. Vogt [22] specifies yearly swing must be lower than 5–6 °C within the 8–12 °C interval for white wine and 12 °C for red wines. Christaki and Tzia [23] show the temperature under 12 °C helps to reduce the risks in preservation phase. Even though there is no homogeneity in those studies, they all remark the importance of wine being kept at specific temperatures. During the wine-aging process, the wine is often kept in non-conditioned casks (usually wooden barrels), therefore the wine temperature follows the temperature trends of the room containing the casks. In the past, in order to keep the temperature within the interval suitable for the wine preservation, aging rooms were built underground [24] to take advantage of the ground thermal inertia. Nowadays, aboveground rooms, provided with air-conditioning systems, are often preferred because of both high precision in temperature control and lower construction costs than underground cellars. In both cases, conditioned and unconditioned rooms, the environment temperature trend affects the wine-keeping and wine-aging processes. Recently, also for this reason, several researches used energy simulation programs to predict temperature [10] and humidity [25] in wine aging rooms.

Despite the non-homogeneity of suggested temperatures found in scientific literature (depending on different conditions of site, product and quality), several authors use 1 °C as order of magnitude for their research. For this consideration, 1 °C has been taken as reference value for the tolerance in this study, therefore sensors with accuracy value included in ±1 °C have been chosen. The chosen sensors are stand-alone-data-logger PCE-HT71 with following characteristics: resolution 0.1 °C, accuracy ±0.5 °C, measurement field −40 °C/+70 °C, memory 16,000 records. Even though these data loggers can measure and record both temperature and relative humidity, in this research are used just as thermometers. Before the survey started, all the sensors were tested in different environments and they all returned values of temperature with average differences lower than 0.1 °C.