Applied Acoustics 76 (2014) 262–273

Contents lists available at ScienceDirect

Applied Acoustics

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

The effects of air temperature and humidity on the acoustic design of voice alarm systems on underground stations

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ARTICLE INFO

Article history:
Received 6 June 2013
Accepted 23 August 2013
Available online 18 September 2013

Keywords:
Air absorption
Underground station
Voice alarm system
Climatic condition

ABSTRACT

Sound attenuation of air due to climatic conditions is often assumed to be constant and/or negligible in the electro acoustic design of voice alarm (VA) systems. However, air attenuation variations can be significant in large underground spaces and particularly as the frequency increases to the mid to high frequencies which are the most relevant to speech intelligibility. This investigation evaluates and quantifies the impact of the variability of the most influential climatic parameters, air temperature and relative humidity, on the performance of VA systems in underground stations. Computer simulations were employed to predict the effect of varying these climatic parameters on key performance metrics. Results demonstrated a significant increase in the values of reverberation time parameters with both temperature and humidity, at frequencies critical for speech intelligibility. Consequently the values of speech intelligibility related metrics decreased with rising temperatures and humidity. Hence, the study shows how ignoring temperature and humidity effects can lead to calculation errors in the design of VA systems. These errors could cause over-specification of the absorption required of surface materials, and the inaccurate prediction of acoustic and speech intelligibility related parameters.

1. Introduction

Voice alarm (VA) systems are sound distribution systems linked to fire alarm and evacuation procedures, and are designed to distribute speech signals from a source in one or more locations to a number of other locations through a multiplicity of directional loudspeakers. They are a crucial part of the communication and emergency network in critical enclosed spaces such as underground stations, where their main purpose is to deliver effective spoken announcements which provide passenger information and more importantly assist in the safe evacuation in case of emergency.

Numerous electro-acoustic and acoustic factors may contribute to unsatisfactory intelligibility in areas of the station where the VA operate thus rendering the system ineffective.

The attenuation of sound propagating over relatively long distances caused by the sound absorption by air varies significantly and irregularly depending on climate conditions, temperature, humidity and atmospheric pressure [1,2]. The air attenuation becomes greater as frequency increases; thus the frequencies which are the most relevant for speech intelligibility (2, 4 and 8 kHz) are affected. It is therefore important to take account of these environmental factors in acoustic studies of large enclosures. However for the sake of simplicity and convenience these conditions are often assumed constant, and hence the sound absorption due to air is also considered to be constant across the frequency range [3–6].

Most room acoustic simulation programs used in the design of VA systems installed in large enclosed spaces are able to account for air absorption as a function of climatic conditions, as entered by the user. However, these variations are often overlooked by practitioners who assume that those environmental parameters will not influence the VA performance, or that they remain constant over time. Hence the usual practice is to use the climatic default values for air temperature (T, in °C) and relative air humidity (RH, in %) which are, typically, 20 °C and 50% respectively.

However, on underground platforms the climate parameters may vary substantially from month to month and even from day to day partly due to outside climatic variations [7,8]. If these variations are not accounted for, there could be a negative impact on the accuracy of the design predictions and therefore in the performance of VA systems.

To illustrate typical variation of climatic conditions, Fig. 1 shows an example of outside temperature and relative humidity observed at a London Underground station (Heathrow) during a twelve month period. Data obtained from www.weatheronline.co.uk[9].

Gilbey et al. [7] have compared measurements of air temperature on deep platforms on the London Underground with outdoor temperatures, as shown in Fig. 2. It can be seen that air temperature on platforms throughout a typical year ranged from 20 °C up to 32 °C. Fig. 2 presents comparatively annual average data

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0003-682X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apacoust.2013.08.017

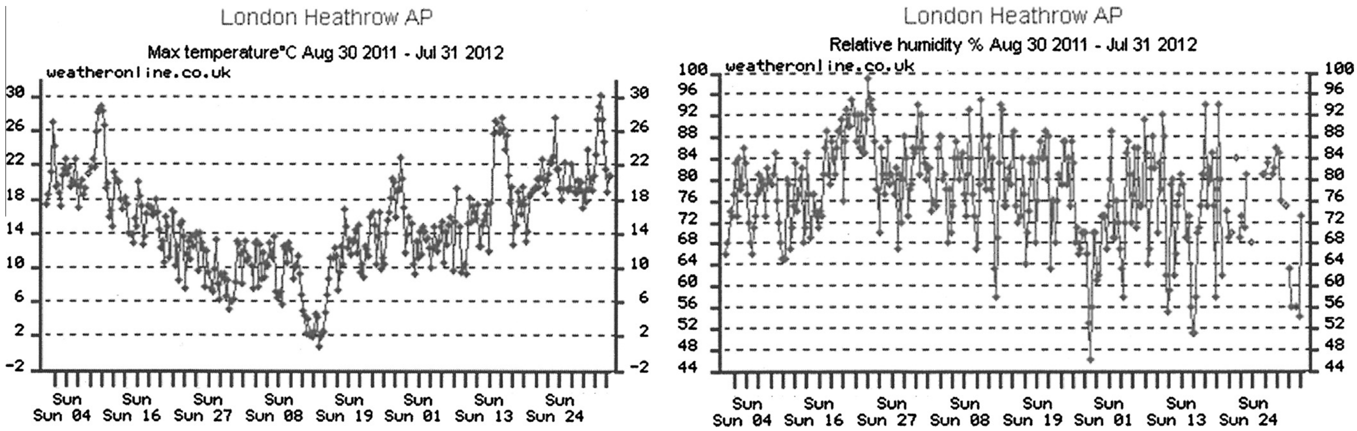

Fig. 1. Maximum temperature (°C) and relative humidity variations in London (Heathrow) during 2011–2012 [9].

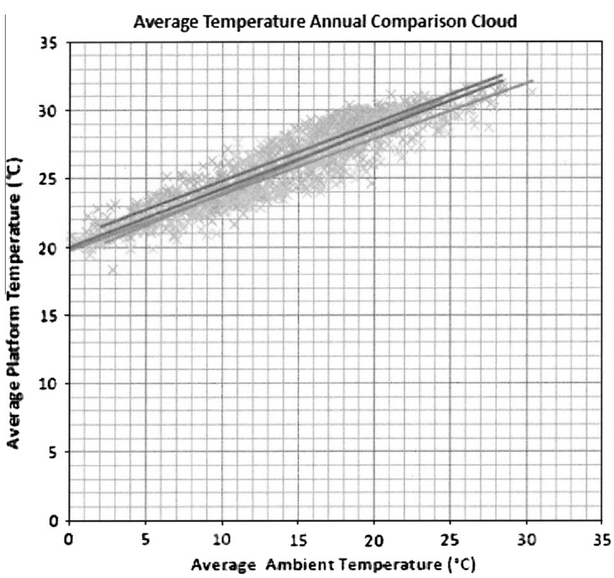

Fig. 2. Scatter data plot of air temperature variations on London deep platforms against outside temperature for four consecutive years. The corresponding four best fit lines are shown. Figure adapted from [7].

variations for four consecutive years of outside and deep platform air temperature [7].

Furthermore, Gilbey and Thompson [8] found that the humidity on London Underground deep platforms follows closely the outside surface conditions.

In previous research investigating the acoustic conditions in underground stations, using mathematical models or computer simulations, most authors report results for a single and constant climatic condition [10–17]. Only Kang [18,19] has reported effects of variations of air sound absorption on acoustic parameters; however his predicted results were obtained using a single omni-directional sound source for one static climatic condition.

The study reported in this paper evaluates and quantifies for the first time the effects of the variability of air temperature and humidity on the acoustic and speech related performance of VA systems on underground platforms.

2. Sound attenuation by atmospheric absorption

2.1. Air sound attenuation

The dissipation of the energy of sound waves attributed to the medium in which they propagate, in this case air, is caused by three mechanisms: shear viscosity, thermal conductivity, and molecular relaxation. These represent different processes in which sound energy is converted into heat or internal energy of the air, thereby decreasing the energy of the sound wave.

The three mechanisms in free air propagation are shown to be proportional to the square of sound frequency [20]. Molecular relaxation is the major contributor to dissipation of energy in the audio frequency range, being dependant on temperature and, more strongly, on the water vapour present in the air, or relative humidity [21]. Air absorption is weakly dependent on atmospheric pressure [2]. Atmospheric pressure and air density are usually assumed constant at normal atmospheric pressure.

The estimated absorption area (A_{air}) provided by the air (or total air absorption in m^2) in a large enclosure is calculated [22] from the air intensity attenuation coefficient m, in m^{-1}, and the volume of air in the space, V in m^3, using the following equation

$$A_{air} = 4 * m * V \ (\mathrm{m}^2) \tag{1}$$

The air sound absorption is also determined by the distance the sound has travelled. The attenuation due to atmospheric absorption A_{atm} in decibels (dB), can be expressed [23] as the following equation

$$A_{atm} = 20 * \log_{10}\left[\frac{P_r}{P_o}\right] = 20 * \log_{10}[e^{(\mu * r)}] = a * r \ (\mathrm{dB}) \tag{2}$$

where P_o is the initial sound pressure at distance $r = 0$; P_r the sound pressure after the sound has travelled a distance r; μ the pressure attenuation coefficient in Nepers per metre; and a the air sound attenuation coefficient in dB per metre.

The attenuation due to atmospheric absorption A_{atm}, in dB, during propagation through a distance d, in metres, is also given [24] by the following equation

$$A_{atm} = \frac{\alpha * d}{1000} \ (\mathrm{dB}) \tag{3}$$

where α is the attenuation coefficient, in dB per kilometre for each octave band at the mid band frequency. ISO 9613-1:1993 provides standardized calculated values of α in dB/m for pure tone frequencies at constant normal atmospheric pressure as a function of the following variables: temperature, humidity and frequency. The estimated accuracy of α for variables within ranges occurring in underground stations is ±10% [2].

In Fig. 3, part of the extensive database provided in ISO 9613-1:1993 has been compiled and presented in curves for the octave bands with centre frequencies in the speech communication range (125 Hz–8 kHz) and relevant temperatures and relative humidity ranges. Fig. 4 presents measured results of air attenuation coefficient α obtained by Harris [1].