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Indoor environment in two medieval churches in Cyprus.

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It is essential to establish the concentration levels of atmospheric pollutants and indoor climate conditions that cause degradation /soiling to items of cultural heritage. In this way indoor environment control strategies for their preservation can be formulated. Limited work has been carried out for the indoor environment of medieval churches in South Eastern Europe.

Valuable works of art, inside medieval churches, are exposed to micro-climate conditions and air pollution levels that differ significantly from outdoors and from other indoor environments due to the specific building characteristics and operation (tourists, mass services, burning of incense, of oil lamps, and of candles).

A research project for the investigation of the atmospheric parameters in old, historical churches in Cyprus was initiated in the year 2002. The project acronym is ARESKE (Study of indoor air quality in medieval churches in Cyprus) and it is funded by the Cyprus Research Promotion Foundation.. Two churches in Cyprus were selected for the investigation. The first is located in a rural area (Paphos) and the other in an urban area (Nicosia) and they house valuable frescos, icons, textiles, books and wooden and metallic artefacts.

Two campaigns were conducted in the framework of the above named project, one in

July 2003 and the second in March 2004. During these investigations the results of the indoor and outdoor atmospheric particle number concentrations and size distributions, determined with a laser optical particle counter with a size range of particle diameters from 0.3-25 μm, the indoor black carbon (BC) concentration and the chemical composition of $PM_{2.5-10}$, are discussed. The chemical composition of $PM_{2.5-10}$ is obtained by sampling the air with impactors and subsequently analysing the filters by ion chromatography. Also, during these campaigns indoor and outdoor O_3, NO_2 and indoor CO_2 and inorganic acids concentrations as well as relative humidity, temperature, and total and UV solar radiation, were recorded.

1. Microclimatic conditions.

Extremes of temperature and relative humidity—and rapid fluctuations in these—can lead to a range of problems, such as warping, cracking and splitting, chemical deterioration, and insect or mould attack. Furthermore, in churches, in Cyprus, light is mainly natural and most of the time solar radiation is strong. Light contributes to the deterioration of works of art in several ways, such as fading, enhancing chemical attack or heating the materials.

The results show that the thick walls of the churches attenuate the effect of outdoor climate conditions, but opening of windows and doors, and people's activities disturb significantly the indoor climate conditions. The observed daily fluctuation of indoor temperature and relative humidity reached in a day 6 ^{o}C and 40% respectively, variations that are deleterious for the works of art. Solar radiation was strong inside the churches, due to numerous windows.

2. Gaseous Pollutants

In Mediterranean countries, such as Cyprus, due to the elevated solar radiation, high temperature, low relative humidity and an always increasing number of vehicles, photochemical air pollutants are serious agents that can threaten works of art. The role of O_3 and NO_2 in degradation of artefacts is well established.

Indoor/Outdoor (I/O) O_3 concentration ratios in the summer were near to unity for both churches, due to enhanced ventilation rate. During winter, I/O O_3 concentration ratios fell to less than half their summer values due to the reduced ventilation rate. In the case of Nicosia the indoor O_3 levels were much smaller than in the Paphos church, due to candle burning. During winter, the I/O NO_2 concentration ratio for the Paphos church was near unity and for the Nicosia church was double that value. Indoor O_3 and NO_2 levels exceeded the proposed air quality standards for the preservation of works of art in both churches. Also, in both churches the I/O ratios of HCl and HNO_3 exceeded unity, pointing out the existence of indoor sources. St. John's cathedral in

Nicosia, with continental climate and the practise of burning candles permissible, appears to have the worst conditions for the preservation of works of art. The indoor air quality model of Nazaroff and Cass was also applied to simulate the indoor O_3 and NO_x concentrations. Model application helps in interpreting the data in terms of air exchange rate, air pollutant deposition velocities and indoor sources.

It is worthwhile to note that the observed indoor O_3 levels and NO_2 levels can adversely affect the human health, especially the health of priest and elderly people, which stay for a long time inside the churches.

3. Particulate pollutants

Furthermore, the deposition of airborne particulate matter damages items of cultural heritage, either by building up dark deposits on their surface, or by attacking them chemically. These harmful effects may be irreversible. Especially for fine particles (including soot particles) it is difficult to remove them from the surfaces of artefacts. It is worthwhile to note that a significant amount of resources of the archeological authorities in Cyprus are consumed in cleaning processes.The degree of degradation of the aesthetic value of the works of art depends on particle size, number concentration, chemical composition, and the nature of near- surface air flow. Research on this field in the churches' atmosphere is crucial to the implementation of mitigation strategies.

The results for airborne particles corroborate that the churches are unprotected against particulate matter pollution. Indoor particulates emanate from numerous sources, including infiltration from outdoors, visitor debris or deterioration of building fabrics and contents. Especially in these churches, serious indoor sources of soot and other particulate matter are the burning of candles and incense.

Measurements of the diurnal pattern of particulate matter concentrations show that during church opening times, particles in all size ranges can be transported into the church by visitors and air infiltration, and are re-suspended from the floor due the air turbulence generated by people's movement. Indoor sources of PM were pronounced in winter times, when the air exchange rate was lower than in the summer.

The chemical composition of $PM_{2.5-10}$ reveals that in the Paphos church mainly primary particles were found, whilst in the Nicosia church the particles were formed in situ, secondary particles.

Nicosia's cathedral, where the burning of candles is allowed, the black carbon values exhibited the highest levels. In the Paphos church the burning of candles is not allowed, but the burning of incense and a limited number of burning candles during mass, lead to BC levels that sometimes were higher than the levels in the Nicosia church, due to its smaller volume. Even in the summer, with enhanced ventilation

rate, the black carbon levels were high as far as the preservation of artefacts in both churches is concerned. During mass these enhanced air pollution levels came along with strong fluctuations in microclimatic conditions and the disturbance of the near-surfaces, air flow.

The results denote that mainly, people's movement and the activities that accompanied the mass services in both churches created the highest levels of PM and BC that threaten not only works of art but also human health.