Microclimate for Cultural Heritage

Conservation, Restoration, and Maintenance of Indoor and Outdoor Monuments

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Contents, Abstracts & Keywords

PART I. ATMOSPHERIC PHYSICS APPLIED TO MICROCLIMATE ANALYSIS AND CONSERVATION

Chapter 1 MICROCLIMATE, AIR AND TEMPERATURE

The basic concepts of climate and microclimate are discussed in relationship with the different scales and the interactions with the cultural heritage. The differences between air, water vapour, perfect and real gases are clarified for a better understanding of the approximations used in thermodynamics and how much they may be relevant to the real world and the conservation practice. Most of the Chapter is devoted to temperature: from the definition to practical consequences. The temperature is analyzed as a key variable responsible for a number of physical, chemical and biological deterioration mechanisms; useful to study air-surface interactions and for environmental diagnostics. How temperature may change passing from outside to inside, in a building, a room or even a showcase. Heating a room requires to combine people comfort, conservation needs and sustainability; however, conservation and sustainability are not always compatible with people comfort and a compromise should be sought.

Keywords: microclimate, perfect gases, temperature, chemical kinetics, environmental diagnostics, thermal comfort

Chapter 2A THEORETICAL GROUNDS FOR HUMIDITY

The Chapter presents and discusses the various physical parameters in which humidity may be expressed, formulae and consequences. Common misuse and obscure popular stuff are removed and substituted with appropriate scientific concepts. Physical definitions and the mathematical formulation are friendly presented and discussed for non specialists. The basic comprehension of

the humidity variables is of absolute relevance to understand deterioration mechanisms and conservation practices that will be discussed in the next chapters. The key topics concerned in this Chapter are: partial pressure of water vapour, latent heat, mixing ratio of water vapour and dry air, specific humidity, absolute humidity, relative humidity, dew point, frost point, wet bulb temperature, psychrometric chart.

Keywords: vapour pressure, mixing ratio, specific and absolute humidity, relative humidity, dew and frost point, wet bulb temperature, psychrometric chart

Chapter 2B HUMIDITY AND CONSERVATION

Humidity is one the most relevant factors in conservation because it drives dimensional changes of hygroscopic materials, allows oxidation, corrosion, hydrolysis, bioinfestation and other deterioration mechanisms. The Chapter presents and discusses the practical use of humidity variables in environmental diagnostics and cultural heritage conservation. After having considered the water vapour in air, and the moisture exchanges with objects, the moisture content in materials is analyzed, and in particular making reference to wood and wood dimensional changes, paper degradation for environmental dampness or flood waters. Liquid water, frost, evaporation, condensation and the formation of monolayers of water filming on the surface of metals, glass and other materials is also discussed, with examples including the organ pipes. A key question concerns the best type of microclimate for conservation and the European standard EN15757:2010 that gives priority to the historic climate is consequently discussed.

Keywords: use of humidity variables; dimensional changes of hygroscopic materials; corrosion; wood; paper; metals; pipe organ, biological habitat; historic climate, European standard EN15757:2010

Chapter 3 PARAMETERS TO DESCRIBE AIR MASSES AND VERTICAL MOTIONS

New variables are introduced for a better thermodynamic representation of the air in the case we are interested to a wide to large scale, or to sites at different altitude above the average sea level, or we need to interpret weather maps for survey purposes. The parameters are: equivalent temperature, potential temperature, equivalent-potential temperature, virtual temperature. The adiabatic, sub-adiabatic and super-adiabatic gradients are also discussed in terms of atmospheric stability.

Keywords: equivalent temperature; potential temperature; equivalent-potential temperature; virtual temperature; adiabatic, sub-adiabatic and super-adiabatic gradients

Chapter 4 RADIATION AND LIGHT

Radiation is considered in terms of thermal emission from bodies (infrared radiation), or in the visible band (luminous) or ultraviolet radiation. Astronomic motions of the sun and irradiation on vertical, horizontal or tilted surfaces, at any orientation. Sunlight penetrating through windows and its changeable colour. Exhibition lighting, types of electrical light sources (e.g. incandescent, halogen, metal halides, fluorescent, solid state LED) and their use for exhibition and restoration purposes. Optical filters for lamps and windows, and optical fibres.

Deterioration mechanisms caused by light, including overheating and drying, colour fading, convective motions, surface deposition and blackening, biological life, development and control of algae in damp environments.

Keywords: Sun, thermal emission, exhibition lighting, visible IR and UV radiation, electrical lamps, optical filters, optical fibres, algae, chlorophyll.

Chapter 5 PHYSICS OF DROP FORMATION AND MICROPORE CONDENSATION
The curvature of a water meniscus governs the equilibrium pressure of water vapour, favouring or opposing to condensation. The phenomenon is regulated by the Kelvin equation that is discussed both for positive radii of curvature, i.e. drops in clouds or fog, or negative, i.e. micropores. The matter is further explained with the example of bubbles and ebullition. The behaviour of internal and surface pores is discussed for various forms of pores. Reversible and irreversible condensation/evaporation cycles. Adsorption isotherms are related to micropore condensation and evaporation. Weathering phenomena, especially in stones, are governed by condensation-evaporation cycles, as well as freezing-thawing cycle, all of them described by the Kelvin equation.

Keywords: Curved water meniscus, Kelvin equation, pore condensation; condensation/evaporation in pores; freezing-thawing in pores; adsorption isotherms; stone weathering.

Chapter 6 ATMOSPHERIC WATER AND STONE WEATHERING
This Chapter deals with atmospheric water and stone weathering. The first topic is the formation of acid rain in clouds (rainout) and the acidification of drops while they fall through the atmosphere (washout). The synergism between wet and dry deposition determines the formation of black, gray and white crusts on the monument surface. The next topic concerns how rainwater penetrates the capillary fringe and internal porosity of stones and in particular the capillary suction and the physical and chemical remedies. The efficiency and the problems in connection with a physical barrier, chemical impregnation and electroosmosis are discussed. The last mechanisms considered concern salts and contaminants, the equilibrium vapour pressure over a solution and the effects of sea spray on monument weathering. A list of popular error and misunderstanding that should be avoided is discussed.

Keywords: acid rain, rainout, washout, capillary rise, osmosis, solution, sea spray.

Chapter 7 ATMOSPHERIC STABILITY AND POLLUTANT DISPERSION
Air pollution is critical for monument conservation and this Chapter provides the basic information to deal with the transport, dispersion and deposition of airborne pollutants. The vertical temperature gradients and the wind intensity and turbulence determine the atmospheric stability and the plume behaviour. The situation is complicated in the presence topographic inhomogeneities or cities with the generation of heat island or aerodynamic disturbances. Parametrization is made concerning wind friction, vertical transport of momentum, sensible and latent heat. A practical, bulk evaluation of the plume dispersion is easily made with the support of the stability classes to evaluate the atmospheric stability after some simple indications concerning the radiation balance and the wind mixing. Strong insolation generates atmospheric instability; net radiative loss generates stability; strong wind mixing or cloud cover generate neutrality. The stability classes established in Brookhaven, or proposed by Pasquill, and subsequent extensions are presented and discussed.

Keywords: Atmospheric stability; stability classes; plume dispersion; air pollution; Pasquill stability classes

Chapter 8 DRY DEPOSITION OF AIRBORNE PARTICULATE MATTER: MECHANISMS AND EFFECTS
The various physical mechanisms contributing to the deposition of particulate matter and soiling are presented and discussed in detail to pinpoint major risks and mitigation remedies. The key mechanisms discussed are: random walk and Brownian diffusivity; thermophoresis governed by temperature gradients; diffusiophoresis governed by moisture gradients; Stefan flow governed by condensation; gravitational settling for the weight of coarse particles; electrophoresis in the presence of electric charges; photophoresis induced by light; aerodynamic deposition for the inertial

motion of coarse particles and other adhesion mechanisms. A series of discussions is made concerning how soiling develops, the distribution of suspended particles in still air, the adverse effects related to lighting, heating, ventilating and air conditioning and the inappropriate position of paintings. Finally, the problem of very large particles, i.e. uplifting of dust and sand, the wind erosion and the kinetic energy in sand blasting. The case study of the Great Sphinx in Giza provides useful examples of the different behaviour of fine, medium and coarse particles in wind erosion.

Keywords: particle deposition; soiling; surface blackening; deposition mechanisms; wind erosion; sand blasting

Chapter No 9. CONSEQUENCES OF THE MAXWELL-BOLTZMANN DISTRIBUTION
The Maxwell-Boltzmann distribution of molecular energies is responsible for the similar mathematical formulation of apparently different mechanisms: the distribution of molecules by velocities, the thermal emission of bodies, the Arrhenius equation, the liquid state of water, and the law for ideal solutions. It helps to understand ebullition and freezing, and the behaviour of the water vapour. The molecular representation explains how relative humidity is related to both the temperature and the distance between H_2O molecules.

Keywords: Maxwell-Boltzmann distribution; thermal emission of bodies; Arrhenius equation; liquid state of water; vapour phase; relative humidity

PART II. PERFORMING MICROCLIMATE FIELD SURVEYS

Chapter 10 INTRODUCTION TO FIELD MEASUREMENTS
From theory to practice: introduction to field surveys and instrumental measurements. Different purposes of weather stations and specific needs for cultural heritage monitoring. Type and presentation of data in terms of averages and frequency, sampling protocols, e.g. interval between subsequent readings, aliasing, Nyquist frequency, length of the observation period, response time of a sensor and consequences in the output reading of thermometers and hygrometers; precipitation roses; percentile representations; drawing air temperature and other isolines for environmental diagnostic purposes. An essential glossary of the key terms is reported at the end.

Keywords: weather stations; instrumental observations; sampling protocol; response time; precipitation rose; percentile distribution

Chapter 11 MEASURING TEMPERATURE
This Chapter is focused on temperature measurements either in air or on the surface of objects. A part is concerned with outdoor measurements at the surface and aloft (with radiosondes, kytoons and other tethered balloons). A section is devoted to thermometer screens to shield sensors against solar radiation and precipitation. The rest of the Chapter deals about the general problem of measurements concerning cultural heritage and the novel EN15758: 2010 standard. According to this standard, contact thermometers are necessary for polished metals and are possible for stones; quasi-contact thermometers should be used for vulnerable surfaces having medium-to high emissivity; remote sensing (e.g. pyrometers, thermocameras) is possible especially in the absence of scaffolding, but only high-quality instruments should be used. All instrument types including the blackbody strip are presented and commented for the best use in conservation and for diagnostic purposes.

Keywords: Thermometer; contact sensor; quasi-contact thermometer; pyrometer; thermocamera, screen, radiosonde; EN15758:2010

Chapter 12 MEASURING HUMIDITY
This Chapter is focused on humidity measurements either in air or on materials of cultural heritage. The first part is devoted to air humidity according to EN 16242: 2012, and deals with: chilled mirror dew point meters for laboratory calibrations; psychrometers for accurate measurements or for checking calibration of secondary hygrometers, i.e. thin film capacitive and resistive sensors. The traditional hair hygrometer is only exceptionally accepted for visual inspection. The second part is devoted to discuss the various methodologies to measure the moisture content in cultural heritage materials, i.e. gravimetry, calcium carbide, conductive or capacitive instruments, microwave, evanescent-field dielectrometry (EFD), nuclear magnetic resonance (NMR), ultrasonic pulses, X and gamma rays, neutrons, thermography and equilibrium proxies. A thorough discussion concerns the limits of calibration of the various methodologies versus gravimetry. Finally, how to measure the time-of-wetness.

Keywords: Dew point meter; psychrometer; capacitive sensor; resistive sensor; hair hygrometer; moisture content in materials; time-of-wetness

Chapter 13 MEASURING WIND AND INDOOR AIR MOTIONS
Instruments to measure wind, turbulence and air movements either outdoors or indoors are described. The first part is concerned about outdoor installing anemometers, and specific instruments to record wind vector components, or average the wind direction, or measure the wind variance especially in view of calculating the dispersion of airborne pollutants. The second part is focused on indoor air motions that are studied with hot wire or hot film anemometers, sonic pulse anemometers, Laser-Doppler anemometers. Some examples are reported of the turbulent convective motions that incandescent lamps or church heaters generate. Finally, some analysis of air turbulence is discussed.

Keywords: wind, air motions, anemometers, hot-wire anemometers, sonic anemometers, laser-doppler anemometers, wind variance, air turbulence

Chapter 14 MEASURING RAINFALL AND WIND-BORNE DROPLETS
This Chapter deals with precipitation measurements, especially rainfall and windborne droplets, and presents the most popular instruments, i.e. the tipping-bucket, the float type and the weighing type rain gauges. Precipitation falling on monuments and building walls is also discussed. The terminal velocity of freely falling drops in air is also presented to show the mechanical impact they have on monument or building surfaces and the action they exert in removing deposited dust and particles. Finally, the wet-and-dry deposition samplers are commented.

Keywords: precipitation, rain gauge, tipping bucket rain gauge, float type rain gauge, weighing type rain gauge, falling drops, wet-and-dry deposition samplers

APPENDIX 1. List of fundamental constants met in this book

APPENDIX 2. Summary of key equations to calculate humidity variables
A1. Available instruments: psychrometer, barometer
A2. Available instruments: thermometer, RH hygrometer, barometer
A3. Available instruments: dew-point hygrometer, thermometer, barometer
This Appendix provides all equations needed to compute the various humidity variables after the input readings from key instruments, i.e. hygrometer, psychrometer, dew point meter, thermometer and barometer.

APPENDIX 3: Essential glossary

Relevant objects, Museums, Monuments etc. exemplified in Figures

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