Historical timber and earthen constructions in Norway Vapour permeable surfaces –restoration challenges

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ABSTRACT: Weather protection and thermal insulation are major challenges in the restoration of historic timber and earthen structures in the Nordic coastal climate. Vapour impermeable surfaces and thermal insulation in historic timber and earthen buildings have increasingly been causing problems in Norway since the early 1970s. A disturbed water cycle and faulty ventilation have led to mould and wood rot. Healthy buildings have become sick: Sick Building Syndrome (SBS) has spread in Norway's humid coastal climate. The Norwegian Passive House Standard poses the danger that these risks will now increase.
Earthen surfaces, earthen infill and earthen mortars in Norwegian timber constructions have been proven to provide heat retention and moisture stabilisation over centuries of Nordic tradition. Their optimal function depends on the type of heat source, the layout of the building in relation to the local climate, the sun and the heat radiation properties of the building components.
Water, in its continuously changing physical states, serves as a natural regulator and plays a central role in the thermodynamics of our historical architectural heritage. In the future, more attention must be paid to the building physics of the natural water cycle when modernising historical timber and earthen buildings.
Modern buildings increasingly depend on technical improvements such as vapour barrier layers, ventilation technology, non-vapour-permeable coatings and heat pumps to regulate their interior climate. The consequence of these technical changes is that the physical system of the enclosure functions like a machine instead of a breathing organism, subject to the principles of building biology.

Keywords: Material properties, Building physics, Restoration practice

1 INTRODUCTION

This paper describes the energy transfer in all buildings that results from solar irradiation in our atmosphere, taking into account the principles of hydrometeorology.
The paper looks at the role of fundamental laws and natural principles in building physics and describes the conditions necessary for a constructive energy interaction between heat transfer by thermal radiation and the water aggregate cycle in enclosed buildings. The paper argues that these natural processes are beneficial for the interior climate of buildings, in turn reducing the need for mechanical cooling and ventilation and lowering energy consumption and costs. The properties of constructions and chemical structures that enable these natural energy cycles to function properly in buildings are presented and discussed.
In summary, the paper describes how traditional earthen structures with vapour-permeable surfaces are uniquely placed concerning building physics. Most importantly, through the way that water is bound by clay minerals, to support natural heat radiation behaviour and the changing cycle of water aggregates.

The risk of "negative water" should not be underestimated when restoring historical timber and earthen buildings, especially in conjunction with thermal upgrading measures. "Negative water" denotes the undesirable accumulation of water in any physical state at the wrong place at the wrong time, regardless of the type of building. Water penetration may be a product of insufficient or faulty sealing, or a lack of capillary-breaking layers in the foundation, especially in earthen buildings. Similarly, an "over- or underload" of indoor humidity usually produces the wrong energetic effect and can have a negative health impact. For positive energetic water, one needs a largely self-regulating, balanced air humidity. "Positive water" is the energy potential which moves freely and naturally in a heated or unheated space, which positively influences energy transfer in the natural thermodynamic phase cycle: cooling in summer during the day and warming in winter and at night. Earth, as a part of a building construction, always interacts thermodynamically with the natural physical state change of water in each climate zone. It is therefore imperative for engineers and builders to adapt building physics to the conditions of the local climate surrounding the construction. The importance grows as climatic changes become more rapid and volatile. The climate in Norway is extreme and changeable, especially in the north and along the coast. Traditional vernacular architecture has adapted to these conditions over thousands of years. Durable surface treatments are therefore an important historical building technology topic. In traditional Nordic vernacular architecture, the balance between weather protection and necessary water vapour permeability is provided by natural materials: linseed oil, tar oil, cod liver oil, glue-oil emulsions. In the 1960s, however, more and more water vapour impermeable materials were introduced, mostly carbon-based solutions. Building physics problems such as Sick Building Syndrome (SBS), which emerged in the 1970s, have become increasingly apparent since then. The weather facade of the residential building at Smedbakken 5 has

01 The façade of Smedbakken 5 in Trondheim built in 1846: approx. 40-year-old paint that acts as a vapour barrier and visible damage to the building physics caused by disturbed micro-meteorology: frost wedging, cracks and flaking of the paint (source: Adresseavisen)

02 All of the geometric envelopes of the 175-year-old residential house are affected due to the micro-meteorological reversal of the vapour permeability and the following change of the dew point. (Source: Author)

been "weatherproofed" at least twice using a closed vapour impermeable solution. The restricting effect on the state change of water from liquid/gaseous to solid when freezing is irreversible: the natural water cycle was out of control. Wooden and earthen materials in a construction attract and release moisture by way of naturally occurring capillary processes. However, unnaturally concentrated condensation may create a dew point at the coldest layer of the walls, floor or ceiling of an enclosure. Over time, the moisture will accumulate at the dew point, consequently leading to strain and damage on the whole structure, sometimes as severely as shown at Smedbakken 5.

Modern building physics and indoor climate "remedies"

Comprehensive modern technical solutions for regulating the artificially controlled indoor climate can be found, for example, in Wang's "Handbook of Air Conditioning and Refrigeration" (second edition, 2000). The solutions it describes attempt to control the micrometeorology of various types of buildings, including that of the residential building at Smedbakken 5.

The "negative water" caused by a lack of circulation in conjunction with the SBS syndrome, is mentioned in the introduction as a problem in building physics: "The Sick Building Syndrome (SBS) received public attention from the 1970s after the energy crisis as a result of a tighter building and a reduced amount of outdoor ventilation air". (Wang, 2000, p. 27)

The strategy proposed in this textbook – like every building physics textbook since then – is to employ artificial and independent mechanical indoor air quality and heating/cooling systems. Water, in all its physical states and changes, is considered the greatest threat: "[…] The key factor is water. […] The result is a 'damp building' which is characterized by dampened materials, damp surfaces, mould, and microbial growth." (Wang, 2000, p. 4)

Modern mechanical systems mimic natural meteorological exchange processes based on changes in the state of water aggregates in relation to a certain air pressure. However, artificial mechanical water vapour circulation systems require continuous maintenance, and their life span is subject to various limitations. Furthermore, that water and metal do not work well together due to oxidation. Vernacular natural ventilation and heating/cooling systems withstand degradation via solar radiation, weather or climate cycle effects, as they allow meteorological cycles to occur in the building structure in interplay with its environment. But as soon as non-vapour-permeable coatings became involved, building physics changed dramatically: "breathing building organisms" got "sick". Typical symptoms include either too dry or too high humidity (evaporation and condensation disturbance), mould, extreme temperature changes, and "strong turbulence" as a product of disturbed air circulation resulting from ventilation problems. With the introduction of structural measures for modern thermal insulation came a corresponding rise in "damage resulting from ignorance of building physics processes and, as a consequence, damage caused by inappropriate heating and ventilation."

"Vapour permeable coatings allow for the evaporation of moisture penetration. It must always be ensured that the outside of the building component (e. g. windows) is coated using more diffusion-open methods than the inside of the building component. If this is not observed, moisture accumulates in the cross-section of the timber." (Source: Building renovation: Identification and repair of structural damage, Michael Stahr; 6th edition, 1999/2015)

Controlling heat and humidity levels based on "thermal resistance" (R- values) has become a universal design means of regulating the transmission of thermal energy that is entirely "independent" of the local climate and all meteorological activity. The case study of the renovation of the house at Smedbakken 5 will show the different approaches that nature, vernacular architecture and modern "*machines for living*" (a term created by Le Corbusier in 1923) take to make micrometeorology work. In science, the term meteorology is used to describe various physical processes in our atmosphere and usually includes the interaction of evaporation, sublimation, and precipitation. Water plays an important role in all these aggregated change processes. The phase change of water by sublimation and deposition occurs in its physical and chemical processes on a change of water by sublimation and deposition occurs in its physical and chemical processes on a micro scale in any gas-filled space and as an interaction with the environment in all conditions with different temperatures, humidity, and air pressure. From a technical point of view, the latent evaporation or condensation energy manifests itself in every part of a building structure in its situational performance in relation to the heat transfer and storage properties of the materials used. Thus, nature regulates the heat transfer of thermal radiation, both in terms of cooling and heating, through mechanisms based on the transfer of energy by absorption, emission, reflection, translucency and change in the state of water aggregate. In modern building physics, however, abstract and calculated technical and mechanical manipulations are used to control these processes, while almost all vernacular architectures have tried to imitate natural heating, cooling and ventilation processes for thousands of years. A simple description of this natural interaction can be found in Wang's work:

"It is well known that temperature also has an influence on the moisture content of many building materials. When a building material absorbs moisture, heat as heat of sorption is evolved. If water vapor is absorbed, then the heat released […] is given (by an addition) where one factor is the latent heat of condensation expressed in the equation by kj/kg. Heat of sorption of liquid water (factor) varies with equilibrium moisture content for a given material." (Wang, 2000, pp. 12-13)

Wang determines: "At a certain time instant, moisture migrating from any part in the building envelope to its surface must be balanced by convective moisture transfer from the surface of the building envelope to the ambient air and the change of the moisture content as well as the corresponding mass concentration at the surface of the building envelope. Such a convective moisture transfer is often a part of the space latent heat cooling load" (Wang, 2000, p. 14).

Any type of fireplace in a traditional house causes this air pressure-moisture transfer effect. The more the heating and cooling of a given space allows for convection, the more low and high air pressures compete. For example, colder surfaces in spaces in combination with warmer humid air always cause natural condensation. The effect is a well-known challenge in construction design and building physics: the "feared" cold bridge or thermal bridge. A company that often encounters micro-meteorological problems, Versaperm Permeability Meter, describes the problem: "The building and construction industry relies heavily on vapour barriers to meet the stringent water and air tightness requirements of modern building practice. But not only can barriers such as paints, films and membranes work differently in changing weather or structural conditions, the results you get in the real world are often far removed from the theoretical published values. […] The flow of moisture can affect both the building's structure and the health of the people who live or work inside. Not only that but it has a considerable effect on thermal insulation: getting it wrong can cause mould, rot, and decay, which have been linked to the rise in asthma and other medical conditions." (Source: www.versaperm.com/applications/paint.php)

In the German-speaking world, expressions such as "barracks climate" or "plastic bag climate" have come to denote such poor examples of building physics. In modern-day "living machines" the natural

meteorology is disturbed and manipulated, leading to symptoms of "disease", e. g. SBS syndrome, as well as possible negative effects on our climate due to disrupted heat transfer from heat radiation: "The urban heat island is partially caused by changes in albedo. The concrete, buildings, and metal have a lower albedo than rural areas with trees and vegetation. There is also less evaporative cooling or transpiration cooling from concrete, buildings, or metal."
"[…] In the atmosphere, there are regions with an excess pressure and those with a deficit pressure. Regions with an excess pressure are termed high pressure and those with a deficit, low pressure. To equalize the pressure, nature moves the air from the high pressure toward that of the deficit low pressure." (Source: Jeff Haby: Theweatherprediction).

Micrometeorology in nature, traditional architecture and modern-day "living machines"

In the Encyclopedia of Vernacular Architecture of the World, in the chapter on climate and its interaction with traditional architecture, we read that architects and engineers have had experience with climate since ancient times in non-traditional architecture: "Since Vitruvius (c. 90-20 BC) prominent architectural theorists have often included select climatic parameters as design determinants without being comprehensive. This continues to be appropriate since designs or performances based on broad climatic type are strongly modified by microclimate. It sums up: climate integrated factor net effects determine a macroclimate or a regional climate."

03 Traditional type of vernacular Nordic timber and earthen construction (earth mortar layer between squared timber in wood framing) with "rapping" (a type of Norwegian clay plaster on wooden surfaces), in the house Smedbakken 5 from 1845/46 in Trondheim, Norway (source: author)

Traditional architecture has reflected the macro-meteorological processes in the atmosphere in all cultures for thousands of years: "Evaporation of water, especially over the oceans initiated a hydraulic cycle. Water vapour transport and precipitation transform solar energy. Winds are major equalizing and dissipating mechanisms of global irregularities in solar radiation. The westerly jet stream in the upper atmosphere is imperceptible at ground level where the general pattern is of warm air flowing toward the poles and cold air from the poles moving toward the equator. The movement of these air masses largely determines local climate." (P. Oliver 1997).

"Vernacular constructions balance temperature and air pressure by strictly adhering to the laws and principles of nature. This human-creative action has been termed a "vernacular response" (P. Oliver 1997).

Energy transport in the atmosphere: isobaric, diabatic, adiabatic, isothermal, and isochoric processes as background for damages caused by dysfunctional "micro-climate" in all buildings

In meteorology, energy exchange and distribution in the changing aggregate state of water is manifested through evaporation and condensation. In our gas filled thermodynamic system, latent heat and sensible (i. e. felt) heat always play a role as part of the element water in its three known assumed states – gaseous, solid and liquid. The ratio of sensible heat and latent heat is expressed by the Bowen ratio. The more gas-filled the environment and the higher the air pressure, the more these processes dominate thermodynamic transfer or interaction. The change of the overall state is the moment of distribution of thermal energy in both forms: cooling and heating. Evaporation, sublimation, and condensation are the processes that trigger energy transfer in nature. Latent heat is involved in melting and evaporation (boiling). The degree of influence in these energy transfers is based on the unusually high amount of potential energy in water and its chemically and physically unusual behaviour in relation to thermal radiation. Energy transfers are caused by continuous heat radiation from the sun and its passive interaction in a particular environment or situation. Therefore, all passive heat radiation is affected at any given time by changes in air pressure, relative humidity, and precipitation of all physical systems inside and outside an enclosure. The character of an enclosure, its hemispherical position, its ability to handle water throughout its change cycle, and the sun's response to thermal radiation are the main factors that describe the actual heat transfer (as a thermodynamic equilibrium process) between objects and their environment. Convection processes have significant effects due to the natural micrometeorological processes in any gas-filled enclosure with physical exchange with its environment. Any heating and cooling system is most efficient if it can maintain the natural thermal equilibrium as long as possible in a given thermodynamic environment or system. The distribution of actively emitting thermal energy must always be as slow as possible. The passive radiation-emitting space must do the same and maintain the energy charge (as latent heat) as long as possible. The faster each active system distributes itself and the smaller the actual radiating surface is, the more it disturbs the heat balance: meteorological phenomena like diffusion, high condensation and evaporation occur at the wrong place at the wrong time, and turbulence occurs. The lighter and less vapour-permeable an enclosure becomes, the greater the need for temperature and moisture management, for example through vapour barriers, heat pumps and increasingly complex ventilation systems. This cycle of water aggregate state change always occurs in all directions through phase transitions: latent heat of fusion, latent heat of evaporation/condensation, enthalpy/sublimation heat and sensible, perceptible heat. The phase transition is always unsteady. Energetic changes occur continuously at any moment, based on the actual interaction in a given climate and its meteorological cycle. This cycle is always determined by one absolute source of radiation: the sun. Artificial spaces have two main alternatives: natural ventilation with free water vapour transport, or mechanically controlled convection and water vapour control. What degree of automation does a vernacular wooden and earthen construction require? Is "*Une maison est une machine à habiter*" (Le Corbusier 1923) given the historical experience of SBS syndrome the goal that should be pursued?

The more a surface is sealed, the more the natural exchange of energy through "transfer", "charge" and "emission", which are controlled by the cycle of water aggregate state change, is disturbed. The amount of energy depends on the thermodynamic transfer in relation to the geometrical configuration, the heat radiation emission value of the material (as liquid, gaseous and solid matter), the surface character in relation to water in its aggregate state behaviour and the air pressure. As in macro-meteorology, the physical system tilts towards or is "forced" to maintain a thermodynamic equilibrium. At any given time, it tries to stabilize the energy transfer through adiabatic and diabatic processes. A good indicator for an artificial space is therefore a balanced relative humidity through undisturbed natural water vapour transfer. Every convective heating or cooling system also increases destructive diffusion. The air flow follows adiabatic and diabatic processes: the higher the pressure and humidity increases, the more the humid air seeks equilibrium. The total amount of energy required to balance these balancing processes is not expressed as "heat loss", but rather in the cooperation between natural micrometeorology and the interaction between active and passive radiant heaters. Due to unsteady micro- and macro-meteorological conditions, the total amount differs at any given time depending on the position, the thermophysical character of the object and the weather conditions/heat radiation input from the sun. A kind of constant factor is the potential thermal mass of the building, i. e. the capacity of latent heat storage by the natural and artificial energy transfer cycles that occur over a certain period of time. Moisture transfer depends on the geographical position and the capacity of the space.

The more vapour-permeable and heavy a geometric object with a low thermal radiation emission value is, the better the energetic balance works according to the principles of micro-meteorology. Ventilation plays an important role due to the natural transport of saturated vapour. It is a physical system that can react extremely flexibly to water vapour pressure and rising and falling temperatures. Experience has shown that clay and wood fibres with surfaces open to vapour diffusion manage these extreme diabatic and adiabatic processes well. These natural building physics instructions were already detailed in ancient times by Vitruvius in "De decrem libri de Architectura". This fundamental knowledge about the micro-meteorological transfer of thermal energy is documented in all vernacular architectures of the world. Clay and earth as one of the oldest building materials "produced" by nature has proven this throughout history: it has its own heat radiation "DNA", high heat capacity (thermal mass) and is able to alternate the aggregate states of water positively in cooperation with the thermodynamic interaction with the sun in every climate zone.

Concluding considerations

Thermodynamic processes in real situations in nature and in all building structures, both vernacular and high-tech, must be strictly adhered to when restoring buildings, as in the case of the house at Smedbakken 5 with its historic timber and earthen construction.

The equilibrium cycle of the changing aggregate state of water, which is caused by all kinds of heat transfer through active and passive thermal radiation, requires particular consideration. As Smedbakken 5 shows, vapour diffusion resistant coatings on timber and earthen constructions should be examined with a critical eye in this context. Bending nature's own physical reality to "match" our mathematical descriptions and scientific models only results in a misguided attempt to improve an already functioning historical traditional building method like the construction at Smedbakken 5. Traditional architecture is practical knowledge conveyed "by hand", which applies the thermodynamic principles of nature (the vernacular response, described by P. Oliver) in a practical manner without the need for intellectually abstract calculations, thus proving its role.

All earth and timber constructions in traditional architecture of all climate zones react through micrometeorology caused by radiant thermal heat transfer in all buildings, following the principles of nature, their specific geometric spatial proportions, and their thermal radiation behaviour.

The actual geometric radiant thermal surface in the aggregate state of water change cycle regulates the entire energy transfer process at any given time. The behaviour of water in its states of aggregation and heat radiation in our atmosphere and its interaction with all kinds of artificial spaces, from vernacular architecture to high-tech machine à habiter, requires more attention in future research, engineering and, most importantly, in practical maintenance.

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