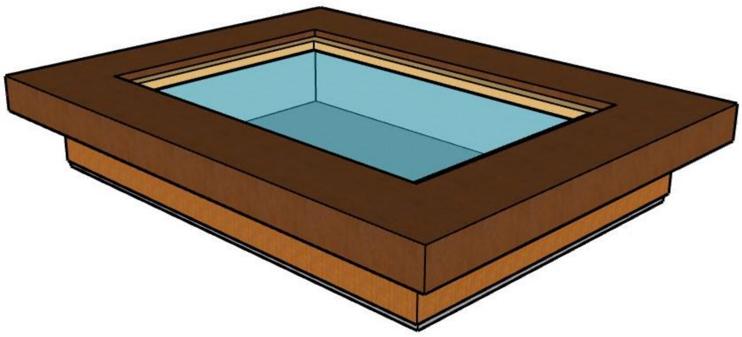
DEPARTMENT OF CONSERVATION

MICROCLIMATE FRAMES FOR PAINTINGS ON CANVAS

A literature review with a case study from Nationalmuseum



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ABSTRACT

The use of microclimate frames for paintings has become more common in the past decades, and it is a good way of protecting climate sensitive paintings during transport, loans, and exhibitions. This study is a literature review that aims to describe the overall practice of mounting canvas paintings in microclimate frames, as well as describe practices at Nationalmuseum, Sweden's largest art gallery, in more detail. The study is divided into two parts, the first one investigating when and why the use of microclimate frames is beneficial. This is done by looking at different agents of deterioration and how they affect paintings on canvas. The second part looks at how microclimate frames are used historically and today, with a focus on the protective effects for climate sensitive canvas paintings, and practical aspects such as material choices and aesthetic considerations. The case study from Nationalmuseum provides an example of what microclimate framing can look like in practice. In addition, conversations with conservators at Nationalmuseum as well as Gothenburg Museum of art have aimed to give a more comprehensive picture of framing practices. In studies microclimate frames have proved to have great effects in stabilising the internal microclimate of the frames and reduce relative humidity fluctuations around the objects. Added humidity buffers are rarely needed for small enclosures like microclimate frames and their addition has become less common. A concern is still the build-up of internally emitted volatile organic compounds. In more recent articles the mitigation of harmful compounds has been investigated. There is difference in opinion on how the degree of seal affects the mitigation, but several sources point to the use of pollutant scavengers, such as activated charcoal, as promising.

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CONTENTS

1. INTRODUCTION

1.1. Background

Microclimate frames can be seen as small display cases for paintings. Today, they are most often housed within the picture frame, but this was not always the case. Microclimate frames have evolved over a long period of time. The designs and materials have varied, but the main goals, to protect paintings from pollutants and unstable climates with fluctuating relative humidity, have remained. In some British and other larger European museums microclimate frames for paintings have been used for many decades, but in Sweden they are a relatively new phenomenon. The use of microclimate frames has only become common in the past decade, and to my knowledge nothing has been written on the subject in a Swedish context.

During an internship at Nationalmuseum I had the opportunity to work on a number of different microclimate frames, both for panel and for canvas paintings, one of which will be presented here. At Nationalmuseum microclimate frames have been used for the past twenty years, and they are today a mainstay in preparing paintings for loan and travelling exhibitions.

The many benefits of microclimate frames include humidity buffering, protection against external pollutants, light, microorganisms as well as reduced impact of shock and vibration during travel. Sustainability issues are becoming increasingly important in all parts of society, museums included. Ways for museums to reduce their carbon footprint can include relaxing the requirements of air-conditioning systems and very strict climate control in museum and storage buildings. To do this, some objects might need separate microclimates in the form of individual enclosures such as microclimate frames.

Although there are many benefits to using microclimate frames, the risk of internally emitted volatile organic compounds (VOCs) is still a concern. How these VOCs affect the enclosed paintings and their components has more recently been dealt with in a few larger research projects including many different museums and partners. Ways to mitigate the effects of these pollutants is another problem that has been looked into in more recent research.

1.2. Previous research

The effects of microclimates and relative humidity in a closed case have been described early on by Padfield (1966), Thomson (1964; 1977) and Toishi (1959) among others. The effects of relative humidity on canvas paintings and their constituents have been investigated by Hedley (1988), Mecklenburg & Tumosa (1991) and Berger & Russell (1986; 1994), and more recently Hendrickx et al. (2016), to mention a few.

Historic overviews on the use and designs of microclimate frames for paintings have been provided by Wadum (1992), Dahlin (2010) and Hackney (2020). Hackney has also written about microclimate framing practices at Tate Gallery (Hackey 1990; Hackney 2007). Different designs have been described by Rothe & Metro (1985), Bosshard (1994) and Sozzani (1997). More recent articles have focused on evaluating existing practices (Harrison 2018) or coming up with a design for solving a specific problem (Toledo et al. 2007; Sá et al. 2019).

The EU PROPAINT project co-ordinated by the Norwegian Institute for Air Research (NILU) was performed between 2007 and 2010 and included several different museums and partners. The rational of the research was "to advance the state of the art in the use of microclimate frames for preventive conservation for paintings and contribute to better standards for microclimate control of paintings on display, in storage, and in transit". The project included environmental measurements inside and outside microclimate frames at 12 different museums to establish the levels of outside and internally emitted pollutants that can be expected. The project also looked at degradation of varnishes due to air pollutants (Dahlin et al. 2010).

Since the PROPAINT project more attention has been given to the mitigation of internally emitted pollutants in enclosures (Cruz et al. 2008; Grøntoft,et al. 2015; Scieweck 2020). The MEMORI project, also co-ordinated by NILU, took place in 2010-2013. This project further investigated the presence of pollutants such as organic acids in museum environments, and their impact on a number of organic materials, as well as some pigments. Ways of mitigating the effects of organic acids in showcases was also looked at in the project (Dahlin et al. 2013). A project conducted by Riksantikvarieämbetet (RAÄ) measured the levels of different pollutants at Nationalmuseum in Stockholm during a lengthy renovation of the museum. In the project Oddy-tests were performed on materials to be used in display cases, and pollutant levels were measured in the galleries and in some display cases (Canosa & Norrehed 2019).

1.3. Aim and objectives

The aim of this thesis is to identify current trends in microclimate framing of canvas paintings, to get a holistic view on practices, its benefits, and potential risks. The objectives are to describe the use of microclimate frames in general and the practice of framing paintings at Sweden´s largest art gallery, Nationalmuseum, in particular, and to provide a short overlook on how framing policy has changed in the past decades. The purpose of the case study is to illustrate when and how paintings are currently mounted in microclimate frames, and which materials are used in the frames.

1.4. Research questions

Based on the aim and current knowledge of the subject, the questions investigated are:

Why are microclimate frames used for canvas paintings?

When and how are microclimate frames used for canvas paintings?

What are the benefits and potential risks of microclimate framing canvas paintings?

1.5. Material and method

This study is conducted mainly as a literature review on the use of microclimate frames for paintings, as well as the effects climate and pollutants have on canvas paintings. The practical part of the study consists of a case study on a painting by Monet in Nationalmuseum’s collection, that was mounted in a microclimate frame prior to going on loan. The case study aims to give insights into framing practices at Nationalmuseum and answer questions about why and how paintings are framed, and which materials are currently used. In addition, examples of different mountings in the collection have been studied to learn how the practice has evolved. Lastly, personal communication with conservators at both Nationalmuseum and Gothenburg Museum of art aim to give insight into framing policies at two big Swedish art museums. These talks have been informal discussions rather than structured interviews.

1.6. Theory

The use of microclimate frames falls into the category of preventive conservation. The notion of preventive conservation is understood as actions taken to prevent future damage or deterioration, but as Muñoz Viñas points out all preservation aims to do that. He instead proposes the notion *"environmental preservation"* as preventive conservation measures are aimed at changing the object's environment and not the object itself (Muñoz Viñas 2005, p. 22).

The ICOM Code of Ethics for Museums states that "*Preventive conservation is an important element of museum policy and collections care. It is an essential responsibility of members of the museum profession to create and maintain a protective environment for the collections in their care, whether in store, on display, or in transit."* (ICOM 2017)

ICOM-CC defines preventive conservation as "*all measures and actions aimed at avoiding and minimizing future deterioration or loss. They are carried out within the context or on the surroundings of an item, but more often a group of items, whatever their age and condition. These measures and actions are indirect – they do not interfere with the materials and structures of the items. They do not modify their appearance"* (ICOM-CC 2008). According to this definition microclimate frames for paintings both do and do not fall into the category of preventive conservation. It is carried out on the surroundings of an object (painting) but does at the same time interfere directly with the materials and structures of an item (the frame). It also modifies the appearance of both painting and frame to some extent.

The European Confederation of Conservator-Restorers' Organisations (E.C.C.O.) states that "*Preventive conservation consists of indirect action to retard deterioration and prevent damage by creating conditions optimal for the preservation of cultural heritage as far as is compatible with its social use. Preventive conservation also encompasses correct handling, transport, use, storage and display. It may also involve issues of the production of facsimiles for the purpose of preserving the original"* (E.C.C.O. 2002).

The ten agents of deterioration, first described by Michalski in 1990, are an important tool for categorizing risks and types of damage. The agents listed by Michalski are Physical forces (neglect and catastrophe), Criminals (thieves and vandals), fire, water, pests, contaminants, radiation (UV and light), incorrect temperature (fluctuations and too high), an incorrect relative humidity (damp: mould, above or below a critical value, above 0% RH, fluctuations) (Michalski 1990). How microclimate frames can reduce (or induce) these risks will be dealt with in section 2.4 and 2.5.

1.7. Limitations

Most of the literature on microclimate frames focuses on panel paintings. The reason that this thesis is focused on canvas paintings is because there is a big difference in humidity response between canvas and panel paintings, and to describe relative humidity's effect on all materials in both would be a huge task. Panel paintings are well known to be very sensitive to fluctuations in relative humidity, and the fact that canvas paintings too can need protection from incorrect relative humidity is more often overlooked. That being said, the designs for microclimate frames are often more or less the same whether they are used for panel or canvas paintings, and the design examples provided in this text are often made for panels. Synthetic and more modern painting materials and combinations will also not be dealt with in section 2.3.1. on painting materials and their response to relative humidity.

Because of a time constraint no climate measurements could be made as part of the case study. As the painting presented in the case study was going on loan the measurements could not be done in this frame. Instead, mock-up frames containing the same materials and air volume would have had to be made to evaluate the performance of the design. This would also need to be done under different conditions, such as original location, during transit and at new location, and ideally for a longer period of time. This was not practical to do as part of this project, which is why the focus is on materials and designs instead of climatic performance.

2. MICROCLIMATES

This chapter explores microclimates in a museum setting and how an unsuitable relative humidity can affect canvas paintings. In addition to incorrect relative humidity, the other agents of deterioration; pollutants, light, physical force, vandalism and theft, water and fire, and pests, are described with the purpose of highlighting the protective effects a microclimate frame can provide.

2.1. Relative humidity and temperature

In museum settings relative humidity is of more interest than absolute humidity. Absolute humidity is the total water vapour concentration in the air. As warm and cold air can hold different amounts of water the absolute humidity does not say a lot about how the humidity will affect museum objects. Relative humidity is the amount of water in a given amount of air relative to the saturation amount, i.e. the total amount of water the air can hold. As the amount of water the air can hold depends on the temperature of the air, relative humidity and temperature are interdependent (figure 1). (Western Australian Museum n.d.)

$$RH = \frac{\text{amount of water in a given amount of air}}{\text{max. amount of water the air can hold at that temperature}} \times 100$$

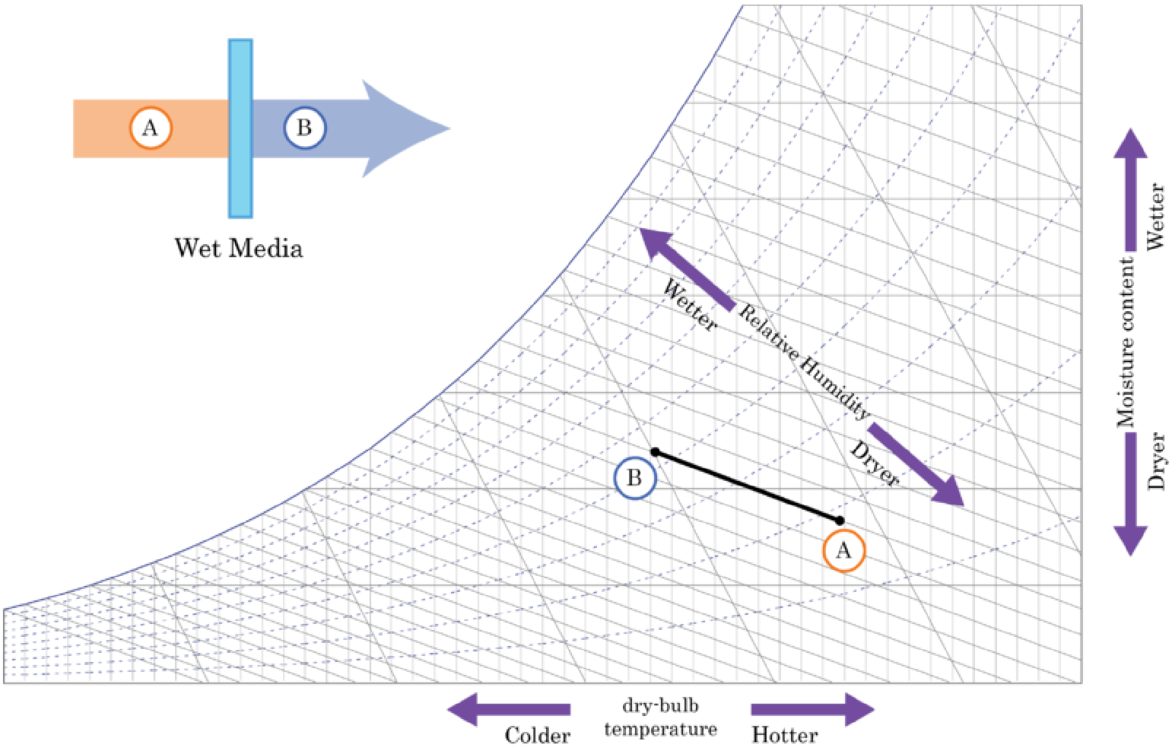

Figure 1:A graph showing the relationship between temperature and relative humidity. As the temperature drops, the maximum amount of water the air can hold also drops. Illustration: Soazig Kaam, CC BY-SA 3.0

2.2. Museum microclimates

As the temperature must be kept within values that are comfortable for museum visitors, lighting be kept at a level that allows for the artworks to be seen, and all other agents of deterioration kept to a minimum, relative humidity is the one variable for preventive conservation that has no optimal value or range (Erhardt & Mecklenburg 1994). Indoor relative microclimates naturally depend on the local macroclimates and can change with seasons and weather. In northern countries like Sweden the inside air can become dangerously dry in winter because of central heating if the air is not humidified. Air-conditioning systems and humidifiers are often used to compensate for the effects of changes in temperature, but these solutions can often lead to uneven distribution of moist air and local variations in climate (Camuffo 2014). Oftentimes the outside walls of museum buildings can get very cold in winter and hot in summer. This can, if the building is not properly insulated, result in local microclimates along the walls in the museums, with high RH in winter and low RH in summer (Mecklenburg 2007). This of course is detrimental for the paintings on these walls that must withstand very great fluctuations in relative humidity. The best way of shielding paintings from the negative effects of outside walls is keeping a large enough gap between wall and painting. 20 mm is recommended for small paintings, more than that is needed for larger paintings (Padfield et al. 2002).

There is no universal value or range of RH that suit all material categories. A climate suitable for one group of objects might cause damage to another, either long term or short term. For inorganic materials the range of acceptable microclimatic variations are more agreed upon and generally accepted, whereas for organic materials there are no set values (Holmberg 1999). 20˚C and 50% RH has long been the ideal conditions for mixed exhibitions, partly because these values are easy to remember (Bickersteth 2014). 55% RH was a long accepted universal value for organic materials provided by Garry Thomson in his 1978 publication *The Museum Environment.* According to Erhardt et al. (2007), this value was mostly chosen as a convenient midpoint between embrittlement at below 40% and mould growth above 70% RH, and the ±4-5% fluctuations Thomson mentions are the limits of what can be expected of an air-conditioning plant to achieve, not what is needed for preserving the objects. The misinterpretation of these values has led to an extremely narrow range for fluctuations that can be expensive and impractical to maintain (Erhardt et al. 2007).

Erhardt & Mecklenburg (1994) point out that the general recommendations of 40-60% RH minimize the most visible types of damage; biological attack, mechanical damage and the efflorescence of common salt, while stating that a lower RH would be more desirable for reducing the slower and less obvious degradation of organic materials. They conclude that any chosen RH for a general collection will be a compromise between different variables. The most important thing is to avoid extreme values and rapid or large changes in RH, but even so some objects may require separate macro- or microclimates (Erhardt & Mecklenburg 1994).

The current Bizot Interim guidelines for hygroscopic materials agreed by AIC, AICCM and Bizot state that a stable RH within the 40-60% range should be kept with fluctuations of no more than ±10% per 24H. Temperature should be kept between 16˚C and 25˚C (ICOM-CC). The ICOM-CC Environmental Guidelines also state that *care of collections should be achieved in a way that does not assume air conditioning (HVAC)* and that *guidelines for environmental conditions for permanent display and storage should be achievable for the local climate* (ICOM-CC 2021).

Michalski (1993) divides incorrect RH into four main categories: damp, RH above or below a critical value, RH above 0%, and RH fluctuations. The dimensional changes in wood are dramatically affected by fluctuating RH, since wood holds much more water than air, volume for volume (Thomson 1964). Other organic materials are also negatively affected by RH fluctuations. How fluctuating RH affects canvas paintings and their components will be described in section 2.3.

2.3. Climate in a closed case

In contrast to the outside world, RH in a closed space with a small air volume is controlled by the absorbent materials enclosed, as they can hold more water than the air. For example paper holds several thousand times more water than air does (Wadum et al. 1998). The water concentration tends to be uniform throughout the enclosed air, which means that the relative humidity can differ locally and be higher in cooler parts of the enclosure (Padfield et al. 2002). The equilibrium moisture content (EMC) is reached when the enclosed hygroscopic materials and the surrounding air are in equilibrium, meaning that the materials are neither gaining nor losing moisture (Harrison et al. 2018). The hygroscopic material to air ratio is critical for maintaining the humidity in the materials. An increased amount of hygroscopic materials in a case will clearly decrease the fluctuations in relative humidity inside a case (Ferreira et al. 2015). In an empty case without absorbing materials a rise in temperature will cause a decrease in relative humidity. In a case with absorbent materials the opposite will happen, as the materials release moisture with elevated temperatures raising the RH and vice versa (Sozzani 1997; Hackney 2020). This is why there is not a risk of condensation as long as there is enough absorbent material in the case, but RH could become dangerously high close to the glass if the absorbent material is at a higher temperature than the rest of the enclosure because glass is slightly cold (Padfield 1966).

A display case is labeled conservation grade when 0.1 air exchanges per day can be guaranteed (Chiantore & Poli 2021). A painting with backboard and glazing will have an air exchange rate of 1 per hour or more (Hackney 2020, p. 187). Not sealing the frame completely means that moisture can diffuse out through the wooden frame or through cracks (Padfield 1966). In a completely sealed case the quantity of water would be unchanged and only move from one enclosed component to another with changing temperatures (Hackney 2020, p. 188). Increasing the air exchange rate just slightly decreases the buffering effect of enclosed hygroscopic materials (Ferreira et al. 2015).

Extreme microclimates can be caused by for example direct sunlight on a showcase or microclimate frame. Direct sunlight on a glazed picture will cause a greenhouse effect, where some of the IR radiation is absorbed by the glazing, raising the heat (Camuffo et al. 2000). Unsuitable lighting (such as tungsten halogen lighting) could also cause significantly higher temperatures and consequently higher daily variations in RH (Thickett et al. 2005). Another situation that can cause extreme microclimates is when a painting is placed directly onto an uninsulated outer wall, where temperatures can be very low or very high, effecting the climate in the case (Padfield et al. 2002).

2.4. Climatic impact on canvas paintings

Canvas paintings are complex composite objects, and each component in a painting will respond to relative humidity fluctuations in a slightly different way. A typical canvas painting consists of a support of canvas stretched on a wooden stretcher or strainer, a glue-size layer, a ground or priming layer, the paint layers and a varnish layer (figure 2). There are many different inherent factors that can make canvas paintings especially vulnerable to fluctuating RH, and some of these will be described in this section. Earlier conservations treatments can also play a role in a painting's moisture sensitivity, as will be described in section 2.3.2.

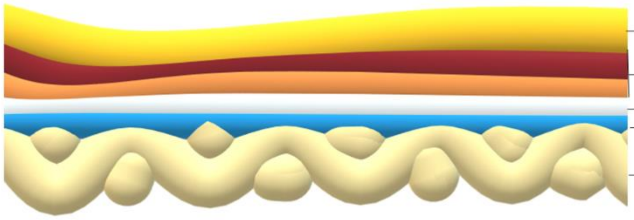

Figure 2: Illustration showing the different layers in a canvas painting. The lowest layer is a woven canvas, the blue layer is the glue-size, the white layer is the ground or priming layer. Two of the layers, red and orange, represent the paint layers. The yellow top layer represents the varnish. The layers are not presented on a natural scale.

2.4.1. Climatic impact on paintings constituents

Canvas and stretcher

The painting canvas consists of fibers, traditionally of plant origin such as flax (linen), jute, hemp, ramie, and cotton, or of animal origin like silk. The fibers are spun into yarns, and the yarns are woven into a fabric (Young 2013). The most common type of weave used in painting canvas is a plain weave, but twill is also seen. For example, Monet used twill for his landscape paintings at the beginning of the 1870's, from which period the painting presented in the case study in section 3.5. is. The canvas is stretched and fastened onto a wooden stretcher with keys or a nonadjustable strainer.

Generally moisture desorption causes an increased tension in canvas and adsorption causes a loss in tension below 80% RH. Above 80% RH tension will rise with increased adsorption, as a consequence of canvas shrinkage (Hedley 1988). The tension usually increases more in the weft direction than the warp direction because the weft usually has more crimp. The swelling of the warp yarns causes the weft yarns to crimp up even more, resulting in shrinkage of the canvas (Mecklenburg & Tumosa 1991). Other factors such as weave density, warp and weft tension and type of glue size also have an impact (Young 2012). Usually canvases with a lighter and more open weave will have a greater tendency to shrink, and start shrinking rapidly at 65% RH, whereas tighter-woven fabrics hardly shrink below 80-90% RH (Berger & Russell 1986). In a painting these numbers will be affected by the subsequent layers. Industrialized canvas production and commercial priming of the canvas have also been shown to have a dramatic response to moisture, causing shrinkage of the canvas with tenting (figure 6.) of the paint as a result (Andersen et al. 2009).

Glue-size and ground

The first preparatory layer applied to a canvas support is usually a glue-size to seal the canvas and make it less absorbing. The size-layer also provides a structural film that stiffens the canvas. Glue-size for canvas is typically diluted animal-skin glue of rabbit, goat, sheep, or glove or parchment clippings, or fish glue (Hackney 2020, p. 11). Grounds can be of many different types but their main purpose is to make the substrate tighter, less absorbent, and more luminous. A gesso-type is generally referring to an aqueous ground and priming refers to an oil-bound layer (Stols-Witlox 2013).

Berger & Russell (1986) showed that a sized canvas is much less affected by dimensional changes than bare canvas. When the glue expands, the canvas fibers contract and vice versa, helping the canvas maintain a more uniform tension (Berger & Russell 1986). Animal glues, such as rabbit skin glue, are dimensionally responsive to relative humidity and can swell and shrink considerably under different conditions, and the size layer has been shown to be responsible for much of the humidity-related damage in a canvas painting. At extremely high humidity the size layer becomes gel-like (Mecklenburg & Tumosa 1991). Hide glue, also proteinaceous, can absorb more than 45% of its mass in moisture (Hendrickx et al. 2016). Gesso made from rabbit skin glue and chalk has a similar response to relative humidity as the size layer, with the addition that a higher chalk-to-glue ratio will yield a smaller dimensional response (Mecklenburg & Tumosa 1991). Grounds generally have a very small absorption because of the low amount of glue and a high amount of chalk, which is non-hygroscopic (Hendrickx et al. 2016).

Paint layers

Most artists' paints will swell with an increase in moisture content and shrink with a loss in moisture content. How much depends largely on the type of paint, what pigment is used and what the pigment to binder ratio is. From 0-75% RH the rate of swelling of oil paints is low, and between 75% and 95% RH there is an increased swelling. Fast drying, stiffer paints, such as lead white, showed less dimensional response to moisture than the more slow-drying earth colours. This means that the swelling response of oil paints diminishes as the paint becomes drier (Mecklenburg & Tumosa 1991).

As showed by Hendrickx et al. (2016), an oil paint consisting of brown umber pigment in linseed oil has a very low moisture absorption of around 5 % at high humidity. The oil paint also has a much higher vapour resistance than the other tested layers in a painting (linen canvas, glue sizing and chalk-glue ground). Vapour resistance is, in addition to a layer's individual capacity to absorb moisture, described as *their ability to transfer moisture to adjacent layers or to the environment* (Hendrickx et al. 2016).

Certain pigments have been shown to exhibit increased light-induced change with an increase in RH. Generally, pigments in oil films are less prone to these changes, as the oil film is hydrophobic and provides a better protection for the pigment particles. Lake pigments are very light sensitive and show an increased degree of fading as RH increases, also in an oil binder. Vermilion showed a greater degree of darkening at high RH, and verdigris in oil exhibited a slight browning at high RH. In lead-containing pigments, such as red lead and yellow lead monoxide, the light induced darkening persisted at low RH. At higher RH these lead-containing pigments would lighten, as the red lead is converted to lead white (Saunders & Kirby 2004).

Varnish

In a varnished painting the varnish layer, being the most exposed, will be more affected by both climatic variations and pollution than the paint layers. Photo-oxidation, causing aging and yellowing of varnishes and drying oils, is favoured by high relative humidity conditions (Dei & Giorgi 2013).

Paintings as a whole

In a painting the paint layers and substrate become a single composite where the components interact. The same type of paint might crack on one type of substrate and not another. There is also a difference in the thickness of the paint layers. A lightly painted canvas will rise in tension as the RH rises because the canvas tends to shrink, and as RH returns to normal conditions the canvas will have less tension and sag. For a painting with heavy impasto the paint film will restrain the canvas and the tension will rise less during increased RH. Instead, the tension will rise as RH returns to normal, resulting in contraction and possible cracks at the weakest points in the paint. For the paint layer to stay damage-free it would need to be more flexible than the support, and the support would need to be stiff enough to hold the paint layers, which is not the case as the paint layers become stiff with age (Berger & Russell 1994).

Most of the moisture absorption and release in a canvas painting happens through the canvas. From there the moisture will travel up into the following layers, size, ground and eventually the paint layers. Absorption and release via the paint layers will always be much slower than through the canvas (Hendrickx et al. 2016). A uniform varnish layer will further hinder the transport of moisture through the front of the painting. A varnished traditional oil painting in a heavy frame can provide almost as much RH stability as if it were glazed (Hackney 2007).

Relative humidity cycling leads to expansion and contraction of the painting (figure 3). In the expansion phase cracks will appear, and the contractions can cause blistering in the paint. Delamination of the cracked paint causes flaking (figure 4). Cupping (figure 5) is another result of delamination and bending of the cracked paint islands (Berger & Russell 1994). Stretcher bar cracks (figure 3) will appear when a sagging canvas is pressed against the stretcher bars (Michalski 1991). Above 80% RH there is a clear risk of the paint layers delaminating from the canvas as it shrinks (Hackney 2007).

Figure 3: A close-up showing stretcher bar cracks and corner cracks typical of a painting that has been keyed out. As this painting is mounted on a strainer and not a stretcher the cracks are likely to be the result of contractions and expansions.

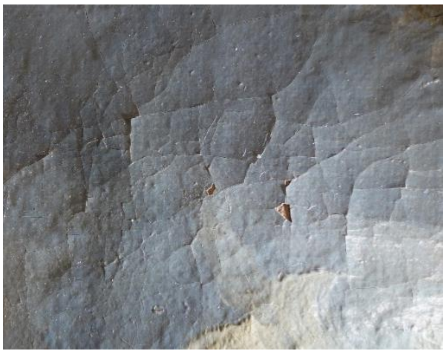 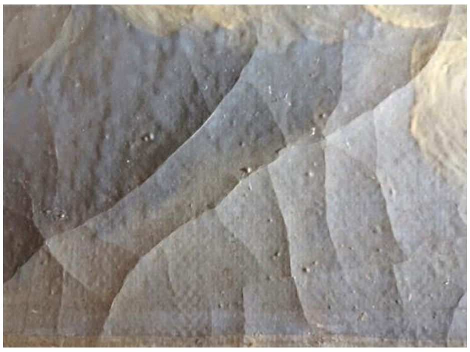

Figure 4:Close-up of delaminating, cracking and flaking paint. Figure 5:Close-up of cupping paint.

Figure 6:Close-up of painting showing cracking, flaking and tenting as a result of contractions.

2.4.2. Earlier conservation treatments

Glue-lined paintings are often very sensitive to high or fluctuating RH. Animal glue is very hygroscopic, and glue-lining will result in rapid response times to relative humidity and sudden loss of tension in the support (Young & Ackroyd 2001). Wax-resin linings have been performed because it was thought that impregnating paintings with a non-hygroscopic material would make them less vulnerable to moisture. But moisture uptake by wax-resin impregnated or lined paintings can cause contraction resulting in bulging and delamination and micro losses in the paint layer (Gregers-Høegh et al. 2019). This is because the tightly spun fibers in a thread normally have more room to expand when subjected to elevated RH, which will make shrinkage more gradual and less pronounced. When the canvas is impregnated there is less room to expand, which causes more pronounced shrinkage at lower RH levels (Andersen et al. 2014).

2.5. Other agents of deterioration

Although the most important reason for mounting a painting in a microclimate frame is protecting it from fluctuating RH, there are other advantages as well. Microclimate frames will reduce the harmful effects of many of the agents of deterioration listed in this section.

2.5.1. Pollutants

Other than providing paintings with a stable microclimate, shielding them from harmful pollutants such as particulate matter and gases is likely to be the most important benefit of enclosing paintings. At the same time, enclosure adds the risk of internally emitted volatile organic compounds (VOCs) harming the objects.

The most common outdoor pollutants that can be found inside museums and cause damage to artworks are sulfur dioxide, nitrogen oxide and dioxide, ozone, and reduced sulfur gases such as hydrogen sulfide (Baer & Banks 1985; Grzywacz 2006). In naturally ventilated buildings the pollutant levels will be as high as outdoors, whereas buildings with HVAC-systems with gas-phase filtration can measure as low as 5% of the outside levels (Grzywacz 2006). The levels of course depend on the location of the building, the amount of outside traffic etc. Particulate matter such as dust, soot, alkaline aerosols, and textile fibers also count as pollutants damaging to cultural heritage objects. New concrete buildings usually have alkaline aerosol particles in the indoor air, that can cause darkening of oil paint films and discoloration of pigments (Baer & Banks 1985). Dust absorbs moisture and pollutant gases (Lee & Thickett 2011).

Pollutants in enclosures

In microclimate frames the levels of outside pollutants will be lower, but the pollutants that find their way into the frames through ventilation paths around the seal will not be evenly distributed in the frame but concentrated around the edges of the painting (Grøntoft et al. 2011). Acetic acid is found in relatively large concentrations inside museums. It is mainly emitted from wood, especially unaged wood, and different plastics. Acetic acid can cause fast alteration in exposed materials, in particular lead, but other materials as well, including organics (Cruz et al. 2008). A study in the MEMORI project measured the effects of acetic acid on unbound lead white, red lead, lead tin yellow type I, malachite and sunfast orange pigments, with colour changes observed in all five pigments (Dahlin et al. 2013).

Formaldehyde is present in small doses in wood but is mainly emitted from wood composites, such as particleboard and fiberboard, due to the urea–formaldehyde adhesive used in their production. Formaldehyde emitted from resins oxidizes to formic acid (Chiantore & Poli 2021). Weaker organic acids like fatty acids from oils and amino acids from proteins could contribute to acid hydrolysis in the enclosures (Hackney 2007). Free fatty acids evaporating from oil paint can create hazy films (fig.7), so called ghost images, on the inside of the glass (Schilling, Carson & Khanjian 1999).

Figure 7: A hazy film on the inside of a glass that has been covering an oil painting in being cleaned off. The films can be caused by free fatty acids evaporating from the oil paint.

The PROPAINT project showed that NO_2, ozone and acetic acid have an effect on the degradation of the natural resins dammar and mastic, while the synthetic resins were less sensitive to these pollutants. NO_2, ozone and acetic acid are oxidants that oxidize the molecular components in the resins, with acetic acid being most efficient at oxidizing natural resins. The pollutants also cause loss of solubility due to cross-linking. The study of varnish degradation in microclimate frames showed that there are both benefits and disadvantages of a tightly sealed frame with a low air exchange rate. Acetic acid is most damaging at high RH and ozone is most damaging at low RH, which means that the buffering effect that the frames provide against external fluctuations in RH is an advantage. The frames will also protect paintings from ingress of oxidizing pollutants (Dahlin et al. 2010). Varying levels of acetic and formic acid were found in almost all microclimate frames in a study by López-Aparicio et al. (2010). All frames had much higher concentrations of these acids than the outside room. Formaldehyde was also found in the frames, although these levels were sometimes higher in the outside room. In addition, a wide range of other VOCs were found in the frames (López-Aparicio et al. 2010)

A study by Grøntoft et al. (2011) similarly showed low values of infiltrating pollutants, but internal emissions of acetic acid and formic acid, as well as lower doses of formaldehyde and many higher–molecular-weight VOCs such as toluene and various terpenes. Because of the small air volume of microclimate frames and the small amounts of pollutants that are added or removed in each air exchange, increasing the ventilation of the frame would not do much of a difference in reducing the internally emitted pollutants (Grøntoft et al. 2011). Ethanoic acid concentrations have been shown to increase drastically in some cases when the degree of seal is below 0.5 air exchanges per day (Thickett et al. 2007). The measurements conducted at Nationalmuseum in 2019 showed acceptable levels of pollutants both inside and outside of display cases. The concentrations of acetic acid, formic acid and formaldehyde were lower in the cases than in the outside galleries, but the cases had not been sealed a long time (Canosa & Norrehed 2019).

2.5.2. Light

Light is often included as a parameter when museum climates are discussed, as light affects temperature and relative humidity. Like the other climate parameters, light cannot be brought down to none, as this would not allow for the artworks to be seen. Organic materials are very sensitive to light, as it causes altering of polymeric structures. Aging of polymers reduces their plastic and elastic properties, causes fading, yellowing of textiles and degradation of wood (Camuffo 2014). As described in the section on microclimates, an increase in relative humidity can increase light-induced fading of certain pigments. UV light is the most damaging, as it is the highest in photon energy. Many glazing options nowadays have UV protection, making glazing beneficial for reducing the harmful effects of UV radiation.

2.5.3. Physical force

Many different types of damages fall into the category of physical force. Marcon (2010) lists five important force-related effects: impact, shock, vibration, pressure, and abrasion (Marcon 2010). The two main causes of mechanical damage during transport are shock and vibration. Shock is caused by single events such as collision or dropping, whereas vibrations are caused by more long-term exposure to transmission of vibrations from for example a motor or a road surface (Saunders 1998). Vibration during transport can be an issue for paintings on canvas. A canvas lacking tension might flap back and forth, which can create damage from impact against crossbars (Green 1991) or potential glazing.

2.5.4. Vandalism and theft

Glazing is an effective protection against many types of vandalism. The most famous example of protective glazing is the Mona Lisa, which is exhibited in a bulletproof glass vitrine (Rea 2019). Although all glazing is not bulletproof, it will still protect paintings from milder forms of vandalism. Glazing also makes it more difficult for thieves to cut paintings out of their frames.

2.5.5. Water and fire

There are extreme situations where no protective frame will be enough the save artworks. But in less extreme cases of fire and water microclimate frames will be beneficial, as they can partly protect the artworks from smoke, soot, sprinkler water and fire-fighting foams. Soot and smoke contain particles of what has burned, as well as byproducts, and they can do a lot of damage to artworks. For example, protein smoke from burnt organic materials can discolour paints and varnishes (Bolstad-Johnson 2010).

2.5.6. Pests

The subgroup of pests is divided into microorganisms (fungi and bacteria), insects, rodents, birds and bats (Strang & Kigawa 2021). For the case of using microclimate frames the first group, microorganisms, is of most interest, although enclosures can of course provide protection from the other two.

Damp conditions for several days can lead to mould growth (figure 8), where the practical danger begins above 75% RH although this depends on the material. A painted surface for example typically needs over 90% RH for mould to develop, whereas it can develop at lower RH in canvas (Michalski 1993). In terms of mould growth, a stable but high RH is more dangerous than RH fluctuations between 50% and 90% throughout the day (Michalski 2004). Continuous RH at 65% could cause mould in about one year, at 70% RH it would take around 100 days and at 100% RH mould growth could begin in just two days (Dixon 2012). Microclimate frames have been shown to be efficient in protecting artworks from microbial deterioration in warm and humid environments. Although mould did grow in three out of five tested microclimate frames within a year of high RH, microbial contamination was higher on the replicas exhibited without protection (Toledo et al. 2007).

Figure 8:A painting showing signs of mould growth. The active mould has been scraped off, leaving dark spots where the attack has taken place.

3. MICROCLIMATE FRAMES

This chapter will look into how microclimate frames have been used historically and today. The focus is on designs and material choices. Microclimate framing practices at two large Swedish art museums, Nationalmuseum in Stockholm and Gothenburg Museum of art, will be described in more detail. The case study from Nationalmuseum aims to show the whole process of mounting a painting in a microclimate frame.

3.1. A brief history

Some of the first examples of backings and glazing of paintings are from the National Gallery in London in the 1850's (Hackney 2020). The reason for this was not achieving a stable microclimate, but protecting the works from the large amounts of dust, dirt and other types of pollution that would enter into the gallery and accumulate on the paintings. A select committee recommended cloth backings attached to the back of oil paintings and that "pictures of moderate size might be covered with glass" (Select committee 1850). There was much difference in opinion on glazing, partly because of aesthetic reasons, but also because a good circulation of air was seen as essential for the preservation of paintings (Select committee 1853). The practice of glazing probably begun sometime shortly after 1850 (Hackney 2020). At The Victoria & Albert Museum, then The South Kensington Museum, back protection of paintings started around the same time, after a large donation in 1856. The donated paintings were back protected with oilcloth to prevent them from coal burning outside and gas lighting inside the museum. Glazing begun roughly around the same time (Powell & Allen 2006).

The first example of a completely sealed microclimate frame is also from the Victoria & Albert Museum. A painting by J.M.W. Turner, Venice from the Canale della Guidecca di Santa Maria della Salute, was in 1892 placed in a microclimate box similar to the microclimate frames of today. The box had nozzles at the bottom for attachment to an exhauster to extract air from the box and create a vacuum. The box has not been opened since its creation, and the painting inside is appreciated to be in better condition than it would be if it had not been framed in this way, based on comparisons to other unprotected paintings from the same period (Dahlin 2010).

The conservation framing policy at Tate has been thoroughly described (Hackney 1990; Booth 1996; Hackney 2007; Mills et al. 2010). For decades now, the approach at Tate has been glazing and backboarding most traditional easel paintings. From using different synthetic boards as backboards for the first half of the 20th century, hardboard was adopted as standard in the 1950's. These backboards were punctured to allow better air circulation, with added copper gauze to reduce dust and pests. The fast-degrading hardboard was changed to oil-tempered hardboard in the 1970's, and sealing the frames was adopted around the same time. As a lighter option for very large paintings Kapaboard has been used (Booth 1996). Since the 1980's rigid backboards attached to a frame build-up have been used in combination with glazing on much of the collection to ensure stable microclimates (Hackney 2007). Booth (1996) also mentions lining the oil-tempered hardboard with Melinex. Low-reflecting scratch-resistant acrylic sheeting is described as being very expensive still, which is why low-reflecting glass is favoured. None of these articles make a distinction between panel and canvas paintings.

Brough describes the framing policy at The National Gallery in 2006, where low reflecting, laminated glass was used for glazing and Lexan for backing boards (Brough 2006). At the V & A the policy around the same time was replacing old, easily broken float glass with UV-inhibiting low-reflecting laminated glass. To facilitate the thicker glass and spacers between painting and glass, the frames were built up with pine coated with acrylic paint. Oil-tempered hardboard with an isolating layer of Melinex was used as backing boards. Only more vulnerable panel paintings are said to be fitted in microclimate boxes (Powell & Allen 2006).

Rothe & Metro describe a display case for panel paintings designed at the J. Paul Getty Museum. This case is a plexiglass bonnet/vitrine mounted to a backpanel and a container for silica gel behind the panel painting. The case has plenty of space around the painting (Rothe & Metro 1985). According to Bosshard, this was the traditional way of exhibiting paintings in show cases up until the 1990s, which could be aesthetically displeasing. The large air volume and moderate seal also made them less efficient in controlling RH than a smaller case would. Bosshard instead proposed a smaller plexiglass vitrine that could be fitted into the frame. He describes it as one part bagged silica gel behind a wooden lattice, one part panel painting, and one part free air space (Bosshard 1994). The drawback of this design was, according to Sozzani (1997), that these cases were very expensive, as they had to be made to order. Sozzani in turn proposed a cheaper design, first used at the Rijksmuseum in Amsterdam. The design used the picture frame as vitrine body with a tightly sealed glazing and backboard, and could be made in-house (Sozzani 1997). This is more or less the design used today, although material choices have varied.

3.2. Frame types

Active and passive humidity control

Humidity control can be both passive and active. Active humidity control is achieved by HVAC systems and other types of machinery (Beale 1992). There are certain disadvantages and risks associated with active humidity control, as the machinery is expensive and can stop working correctly, which can be more harmful than no active control (Bosshard 1994). Passive humidity control is achieved with absorbent materials used as buffers inside cases. Self-buffering cases also fall into this category (Shiner 2007). Although there has been tries at active humidity control in microclimate frames, most are of a passive type, either with or without humidity buffers (figure 9).

Different designs

There are different types of microclimate enclosures for paintings. The terms microclimate frame and microclimate box are often used interchangeably, although microclimate box can also refer to a removable box that is placed in the frame, or a box around both painting and frame. Microclimate package or envelope is used for tighter enclosures using for example a barrier film instead of a backing board, and shadowboxes are larger enclosures that can house both painting and frame (Harrison 2018). Although a backing board and glazing will provide a painting with a microclimate, microclimate frames typically refer to more sealed systems. There are different ways of classifying case designs. The most common division is by air exchange rate (Chiantore & Poli 2021) The air exchange rate of course depends on the level of seal. Cassar suggested a typology based on passive and active air exchange in display cases (Cassar 1984). Wadum (1998) has divided microclimate frames into three categories: buffered frames, frames with no added buffer, and frames with an altered gas content. He further illustrates in simplified drawings the different ways in which a panel painting can be placed inside microclimate frames (Wadum 1998).

3.3. Design components

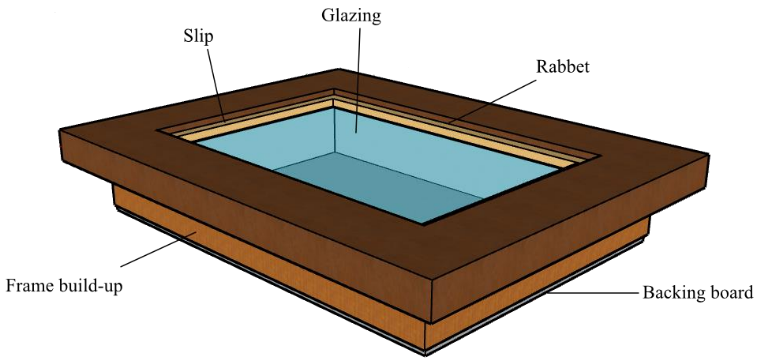

Figure 9:Illustration showing the different parts of a microclimate frame.

Frame

Frames in themselves provide a level of protection to the artworks. They are also often used as part of the case design.

Backing boards

Backing boards will protect the back of the painting from mechanical damage from behind and from dust and dirt falling between stretcher and canvas. They will also protect the back of the painting from pollution that could weaken the canvas support (Daly Hartin 2016).

Harwood & Caldwell (1996) list the most important properties of backing boards as being stability, reversibility, moisture barrier, strength and flexibility, transparency and simple handling. Oil-tempered hardboard, Gatorfoam, polycarbonate twinwall sheeting, polyester sailcloth, thick Melinex, polythene sheeting were all tested for the above mentioned criteria, with the results that all were effective at reducing fluctuations in RH even without glazing, except for the polyester sailcloth. In terms of reducing RH fluctuations, it proved to be more effective to attach the backing to the frame and not the stretcher. Sealing with tape is also more effective than simply attaching the backing board with screws or staples (Harwood & Caldwell 1996). Foamboards, such as Kapaline and Gatorfoam, have been used in the past for their light weight. The foamboards are made from polystyrene or polyurethane foam between card laminates, sometimes resin coated. Foamboards are not suitable for long-term use, as they degrade and give off volatile substances that can harm the artworks in close contact with it (Harwood & Caldwell 1996).

Backing boards fastened to the stretcher or strainer can help reduce the effects of vibrations in the canvas during transport (Green 1991). Glazing in combination with padded backing boards even more effectively reduce the effects of vibrations. Corrugated rigid cardboards or honeycomb cardboards show the best results, whereas thinner corrugated cardboard, polyurethane hard foam core board and polycarbonate multiwall board can have adverse effects (Bäschlin 2011). The same effect that makes backing boards beneficial to paintings subjected to vibrations also applies for paintings that are dropped (Michalski 2005).

According to Green (1991), procedures that are applied directly to the painting are far more efficient at reducing the negative effects of vibration than are packing materials around the objects. Backing boards, loose linings, stretcher linings and padding are all methods used directly to the paintings for reducing the effects of vibration during transport. Rigid backboards effectively reduce the impact of shock, while padding in closer proximity to, not direct contact with, the canvas will reduce the effects of vibrations. Lightweight hard foam, polyester fleece or cushioning foam attached to the backboard are more efficient than loose linings techniques used (Bäschlin et al. 2011).

Most porous materials, such as wood, plywood, hardboard and paper, rise rapidly in their moisture permeability above 60% RH. This can make them unsuitable as backing board materials, especially in humid places, as they can let through 20-50 times more moisture at 100% RH than at 50% RH. This can cause water to penetrate faster at damp periods than it will leave at dry periods, eventually leading to mould growth (Michalski 2004).

Glazing

Traditionally regular float glass was used for glazing paintings, but glazing options are constantly improving. Some important properties of glazing for pictures are reflectivity, strength and weight, colour and ultraviolet absorption (Saunders & Reeve 1994). Low-reflective laminated glass was long favoured. At Tate the recommendation was to use laminated glass for paintings larger than one meter in any direction, because of the risk of breakage. But if the glass is well fitted in the frame, it is actually quite difficult to break glass (Powell & Allen 2006). Glass has the disadvantage of being very heavy, especially laminated glass.

Acrylic glazing options have become more popular in the past decade, with constantly improving properties. Many sources, such as Hackney (2007) point to electrical charge being one of the drawbacks of using acrylic glazing. This has changed, and the museum acrylics of today no longer have this problem. They can be safely used for works of art in friable media without risking displacement of pigment particles. Many acrylic and glass options today also have UV-protection and antireflection properties, and lack the green tint often found in glass (Paisley 2007). The museum acrylics are still quite expensive compared to other types of glazing options (Sá et al. 2019). Another potential drawback of acrylics is that it is more flexible than glass, and if the thickness of the glazing and the distance between painting and glazing have not been matched to the size of the painting there is risk of contact due to bowing of the glazing sheet (Ramsay 2013). This could happen for example when pressure changes during flights (Richard 1994). There is also a risk of bowing due to high temperatures or relative humidity (Paisley 2007).

Buffers

Materials used as humidity buffers can absorb large quantities of water and can in this way be used to maintain a stable RH in enclosures. At high RH these materials will absorb moisture from the air, and at low RH they will release moisture into the air. The most commonly used buffering material in microclimate frames is silica gel (Sá et al. 2019; Bosshard 1994) Michalski mentions the role of buffers in the use of microclimate frames going from a passive form of protection from fluctuating RH to actively seeking to reach a fixed RH target close to 50% in the 1970's, 80's and 90's (Michalski 2004). But the buffers buffer against change, they cannot force an RH higher or lower than the room average (Thomson 1977).

Silica gel is conditioned to a specific RH range before being inserted into the frame or case, but it will not hold RH at a specific value, only retard movements away from it (Piechota 1993). Thomson (1977) recommends about 20 kg of silica gel per cubic meter of case volume, but there is a big difference in how the silica gel is placed. The more surface area of the gel that is exposed, the faster the response (Raphael & Burke 2000).

Sozzani (1997) describes how silica gel could actually have adverse effects at sustained elevated temperatures, as the wood will continue to give off moisture and the silica gel continue to absorb it, potentially leading to dimensional changes in the wood (Sozzani 1997). Fluctuating temperatures could also lead to a “breathing process” between silica gel and painting (Wadum et al. 1998). Without added silica gel and with enough wood in the case, the wood will reach equilibrium with the surrounding air. A painting placed in a small case with silica gel did show more dimensional change than one placed in a case without silica gel (Wadum et al. 1998). The use of silica gel is still advisable if the air volume is very large in relation to the hygroscopic materials enclosed, if the case or frame is very leaky, or if the painting will be placed in an environment with high RH fluctuations (Sá et al. 2019). The use of silica gel is most advantageous below 50% RH, not above it. Thomson does not recommend the use of buffers in areas of continuously high RH in the mould growth range (Thomson 1977).

Pollutant scavengers

The PROPAINT study explored two mitigation approaches to reduce the impact of pollutants inside microclimate frames. The first one was a modified air exchange rate and microclimate frame geometry, and the second one was the use of barrier films and adsorbers mounted inside the frames. Increasing the air exchange would not significantly reduce the concentrations in organic acids, as only very small amounts of pollutants would be removed compared to the overall internal emissions and depositions. Instead, the use of barrier films, such as PET-covered aluminium, in combination with an absorber, such as charcoal cloth, showed effect in reducing the impact of harmful gases (Dahlin et al. 2010).

Alkaline buffers such as calcium or magnesium carbonate can adsorb acid gases that come into contact with them (Hollinger 1994). Activated charcoals are also used to adsorb organic acids. Molecular sieves/zeolite can trap molecules that activated charcoal does not, such as nitrogen dioxide. In a study comparing activated charcoal RB4 and zeolite NaX for the reduction of acetic acid both showed similar efficiency, with activated charcoal having the additional advantages of being cheaper and easier to recycle (Cruz et al. 2008). A more recent study (Schieweck 2020) investigates how different sorbents (pure and impregnated activated charcoal, charcoal foams and cloths, zeolites and molecular sieves) work for reducing a number of different VOCs (Formaldehyde, formic acid, acetic acid, toluene and alpha-pinene) in active and passive mode. The results showed that activated charcoals are superior to the other sorbents, although acetic acid and alpha-pinene could be removed with all of them (Schieweck 2020). The MEMORI project similarly concluded that activated charcoals are the most promising alternative (Dahlin et al. 2013).

Although not a pollutant, oxygen is critical in many deterioration processes. Oxygen-free storage is used for archeological metals, valuable documents and other highly sensitive objects, but can also be a way of avoiding the risk for mould growth and insect infestations. Anoxia would be beneficial for the preservation of painting materials such as canvas, protainacious glues, and old oils and varnishes, but the risk is that it can cause colour changes in some pigments (Thomas 2012). For small air-volumes the most low-cost way of creating an oxygen-free microenvironment is by using an oxygen absorbent such as Ageless. Ageless can reduce oxygen levels to less than 0,01% and maintain that level provided there is no oxygen permeability (Gilberg & Grattan

1994). This can be achieved with barrier films like Escal or BDF 200 (Carrió & Stevenson 2002). Anoxia is currently not common in microclimate frames for paintings because the effects are not fully known.

Monitoring

RH can be monitored by hygrometers with probes placed inside the frames (García-Diego et al. 2016) or small data loggers. A more inexpensive option is placing RH indicator cards or strips inside the frames.

Table 1:Examples of different microclimate frames found in literature and the materials used.

Source	Design	Materials	Buffer
Rothe & Metro 1985	Showcase: Back panel, front bonnet and silica gel container behind panel painting	Plexiglass 6-mm-thick plexiglass using a Rohm & Hass PS-30 cement, a two-component reactive acrylic cement.	4000 g silica gel
Sozzani 1997		Schott Mirogard Protect Magic Glass, a nonreflective, glass-acrylic-glass laminate Stainless steel/ aluminium backplate	
Harrison et al. 2018	Microclimate envelope,	Tru Vue museum acrylic Marvelseal Jelutong glazing bars	-
Harrison et al. 2018	Shadow box	Birch faced plywood box Low reflective laminated glass Marvelseal Outer pine frame Polycarbonate backboard	-
Sá 2019		Oil-tempered hardboard Acrylic sheet Frame sealing tape Clear Colour UV 92 glazing Polycarbonate honeycomb Twinwall polycarbonate and Reemay to hold the silica gel	1370 g silica gel
Verticchio et al. 2019	Aluminium case and frontal glass	Aluminium foil Cardboard Glass	-

3.4. Microclimate framing in Swedish museums

3.4.1. Nationalmuseum

At Nationalmuseum in Stockholm microclimate frames have been used for the past 20 years. The first examples used laminated Mirogard glass and aluminium plates (figures 10 and 11), as well as wooden build ups for keeping the painting in place. This made the frames very heavy and difficult to handle above a certain size. Today, all glazing of paintings at Nationalmuseum is done with Tru Vue Optium Museum Acrylic sheets. Sometimes paintings are glazed and provided with a backing board, but not completely sealed. With the backing boards and the glazing the paintings will be subjected to a type of microclimate, although one with quite a high air exchange rate. Twin wall polycarbonate sheets are used as backing boards for all paintings at Nationalmuseum, regardless of their condition and placement. The material is strong, yet lightweight and easy to cut to size. Another advantage of using polycarbonate sheets as opposed to the formerly used KAPA Line foamboards is that polycarbonate sheets are transparent, allowing easy inspection of the reverse of paintings. It is also a very inexpensive and effective form of protection.

Figure 10:An older type of microclimate frame using Mirogard glass, a plexi glass backing board and an aluminium frame. Photo: Astrid von Hofsten.

Figure 11:An older type of microclimate frame using Mirogard glass, a plexi glass backing board and an aluminium frame. Photo: Astrid von Hofsten.

Sometimes a vitrine is used for paintings, for example panel paintings such as icons that do not have frames. Another reason for choosing a vitrine could be that the frame cannot house a microclimate box. The vitrine in figure 12 was used because two paintings that were to be exhibited together needed protection and placing them in the same vitrine was an easier solution than constructing separate microclimate frames. The vitrines are made in plexiglass, and the wooden back panel is covered with Marvelseal to avoid off-gassing of harmful compounds. The surface is then covered with fabric.

Figure 12:A plexiglass vitrine for climate sensitive paintings. The back panel is a wooden board covered with marvelseal and black fabric. Photo: Astrid von Hofsten.

For constructing the microclimate boxes different materials are used at Nationalmuseum. Balsa wood is most often used as spacers between glazing and painting, and sometimes as build up for the frame as is shown in the case studies further down. This is because the material is soft and easy to cut and shape and has a pH of between 5.4 and 7.2 (Tétreault 1999). Its light and neutral colour makes it easy to paint a desired hue. The disadvantage is that it crumbles a lot if not cut with extremely sharp tools. It is also easily compressed and does not recover its previous width after prolonged stress, as well as being highly absorbent (Chock 2017). Other types of wood, such as lime wood, have been used as well. Especially for external build-ups on the frame to house the painting a harder wood type than balsa wood is preferable. The walls of separate microclimate boxes that can be inserted into the frame have also sometimes been constructed of other types of wood. The wood should ideally be as close to pH neutral as possible, although it can be sealed off to some extent.

Fish glue is used for adhering balsa wood spacers and other loose materials placed inside the microclimate boxes. Gouache paint is used for painting spacers and other elements placed inside the boxes, because it is opaquer than watercolour. Self-adhesive felt in viscose or polyester is used for cushioning and felting the rabbet. Sealing off wooden surfaces inside the boxes and sealing gaps to prevent leakage is usually done with an archival aluminium tape with a paper side. Sometimes the boxes are sealed with Marvelseal 360 (figure 13), which is a plastic and aluminium barrier film used for sealing off wood in different types of enclosures. Marvelseal 360 is aluminium foil coated with nylon on one side and polyethylene film on the other, and it is adhered with heat (Tétreault, 2019). Marvelseal is also used for sealing off wooden boards used in display cases for paintings.

Figure 13:Marvelseal placed on a wooden board to be used as backing for a vitrine (left) and Marvelseal ironed onto the board (right).

Figure 14:Back of a painting with a twin wall polycarbonate sheet as backing board.

At Nationalmuseum, sealed microclimate frames are not used for paintings in storage, where the climate is controlled and no sudden fluctuations in relative humidity are to be expected. Paintings that are especially climate sensitive and are to go on loan or exhibition can be protected in this way. Even if the institutions receiving the loan have good climate control the transport could cause stress to climate sensitive paintings (Informant 1 & 2).

3.4.2. Gothenburg Museum of art

At Gothenburg Museum of art microclimates for artworks have been applied for the past 15 years. As there are some problems with cold walls and condensation at the museum, protecting the backs of artworks has been the main focus. This is done with sealed polycarbonate twin wall backing boards sealed with aluminium tape. Using aluminium tape and adhesives directly on the original frames is avoided. Relatively few paintings are glazed, this is done mostly for paintings going on loan. A reason for glazing could be a very high insurance value, friable paint or that the transportation to the exhibition or the exhibition environment is considered risky for the painting. Glazing is done with Tru Vue museum acrylic, and balsa wood is used for spacers. The frames are rarely well-sealed, and often glazing and backing boards are used without sealing at all. But the policy at the museum has moved towards more sealed cases in recent years. For works of art on paper completely sealed enclosures have been adopted, and these have had tremendous effect on the preservation of the works, where previously buckling paper is now staying flat. Evaluating the effects on paintings is more difficult, but no negative effects have been discovered (Informant 3).

3.5. Case study: a microclimate frame for a painting by Monet

This case study was chosen to be included here to give an idea of what microclimate framing can look like in practice. Not all paintings are framed the same way, what matters is the individual challenges and needs of the paintings. The painting presented here, a landscape by Claude Monet with inventory number NM 2513, is a popular painting that has been requested for loan on multiple occasions. This microclimate frame was constructed when the painting was going on loan to the Zorn Museum in Mora.

Figure 15:The painting by Claude Monet with inventory number NM 2513 without frame. The new microclimate frame seen in fig. does not cover much of the edges. Photo: Anna Danielsson/Nationalmuseum.

Inventory number: NM 2513

Artist: Claude Monet

Title and year: From the Voorzaan, 1871

Material: Oil on canvas

Painting size: 34 x 73 cm

Frame size: 45 x 85 x 13 cm

Figure 16:(Left) The painting (NM 2513) in its frame before intervention. Photo: Anna Danielsson/Nationalmuseum.

Figure 17:(Right) The painting in its frame after intervention. The slip is clearly a bit deeper because of the glazing bars/spacers, but there are no visible disturbing reflections from the glazing. Photo: Anna Danielsson/Nationalmuseum.

The Claude Monet painting of a landscape from the Voorzaan with inventory number NM 2513 (figure 15) is a smaller oil painting on canvas that has been glue lined. As glue lined paintings are more sensitive to changes in relative humidity, it was decided that the painting would be mounted in a microclimate frame before going on loan.

The frame is an original, richly ornamented gilded frame with a slip (figures 16 and 17). The painting is slightly too small for the frame in its current state, and there are gaps along some of the edges. When fitted inside the frame, the painting is not sitting on the felted rebate, but instead scuffing against the edges of it. This means the rebate of the frame would need to widened in any case, making this an optimal candidate for a separate, removable microclimate box (figure 22). Not all frames can house such creations, often the frame is a very tight fit with no room for box walls between painting and frame. Figure 18 shows an illustration of how the microclimate box is constructed. The whole process of mounting the painting in its microclimate box is shown in figures 19 to 22 on the next pages.

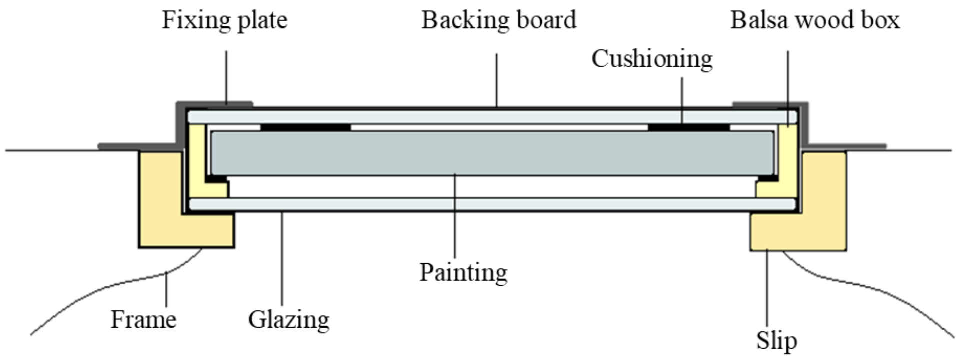

Figure 18:Illustration of the case design for NM 2513. The balsa wood box is fitted inside the rabbet of the slip, which is fitted inside the rabbet of the frame. The sides of the box are sealed with aluminium tape.

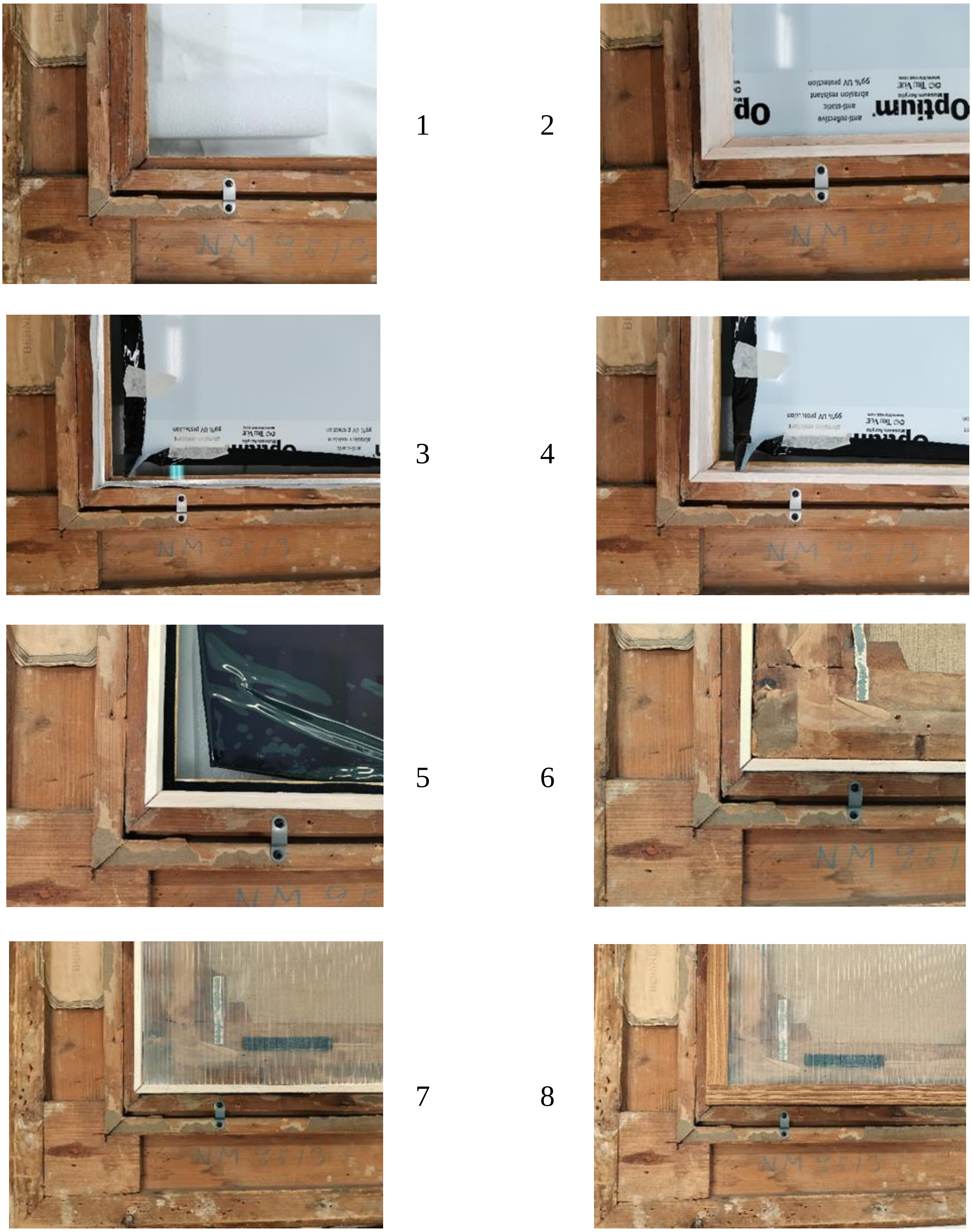

Figure 19:The different steps in the process of mounting the painting in its microclimate frame. For explanations see next page.

Figure 19. 1. The frame slip rabbet is cleaned of old tape and felt.

Figure 19. 2. A sheet of Tru Vue Optium Museum Acrylic inserted into the rabbet (with protective plastic still on). Battens of balsa wood are rebated and miter joint at the corners.

Figure 19. 3. Protective plastic peeled back. Aluminium tape is painted with gouache paint in a golden hue and fastened to the underside (front) of the glazing. The edges are folded up to be adhered to the balsa wood box.

Figure 19. 4. The underside of the balsa wood box is painted with gouache paint in a golden hue and at the sides of the spacers.

Figure 19. 5. The rabbet of the balsa wood box is taped with self-adhesive felt tape and the protective plastic is removed from the glazing.

Figure 19. 6. The painting is inserted into the box after having been dry cleaned.

Figure 19. 7. A piece of twin wall polycarbonate sheeting is placed on top of the wooden box.

Figure 19. 8. The box is sealed with aluminium tape painted with vinyl paint to resemble a wooden structure.

Figure 22:The balsa wood box with glazing and protective plastic. The box is a separate unit that can be lifted out of the frame.

Figure 21: (above) Painted aluminium tape.

Figure 20:Sideview of the finished microclimate box placed in the rabbet of the slip.

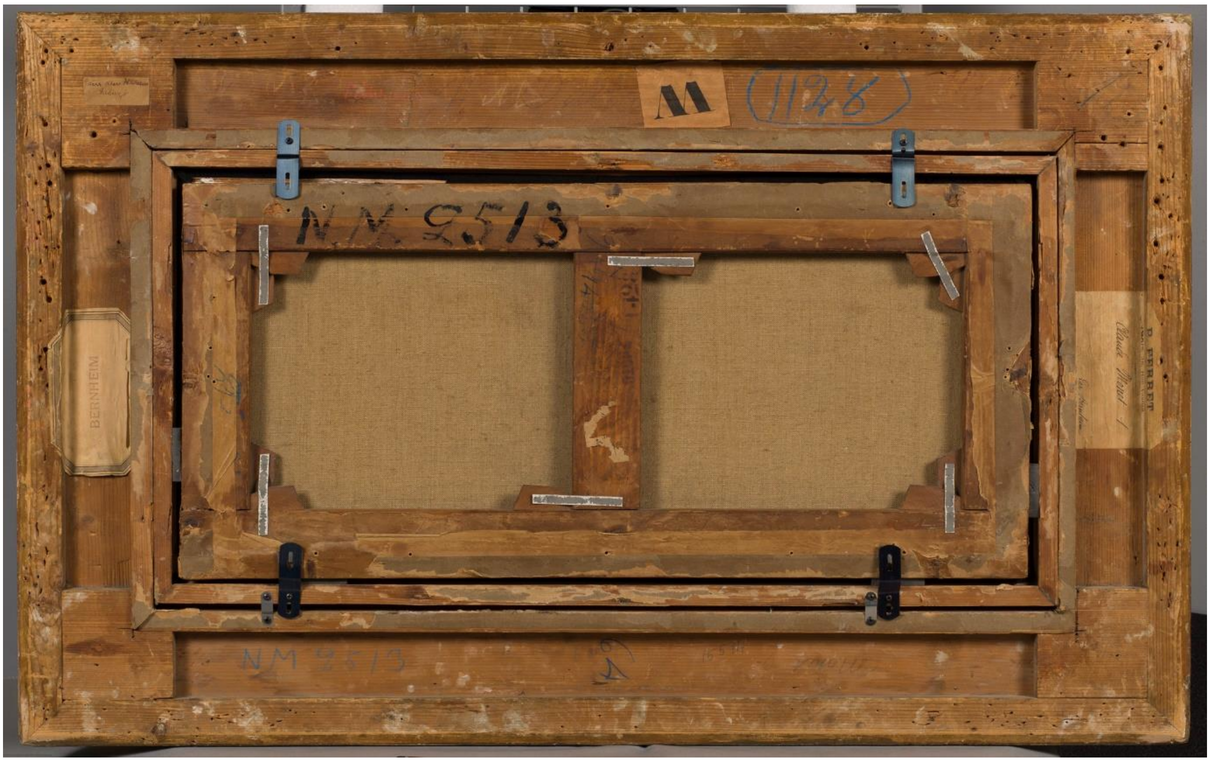

Figure 23: The back of the Claude Monet painting with inventory number 2513 in frame before mounting in its microclimate frame. Photo: Anna Danielsson/Nationalmuseum.

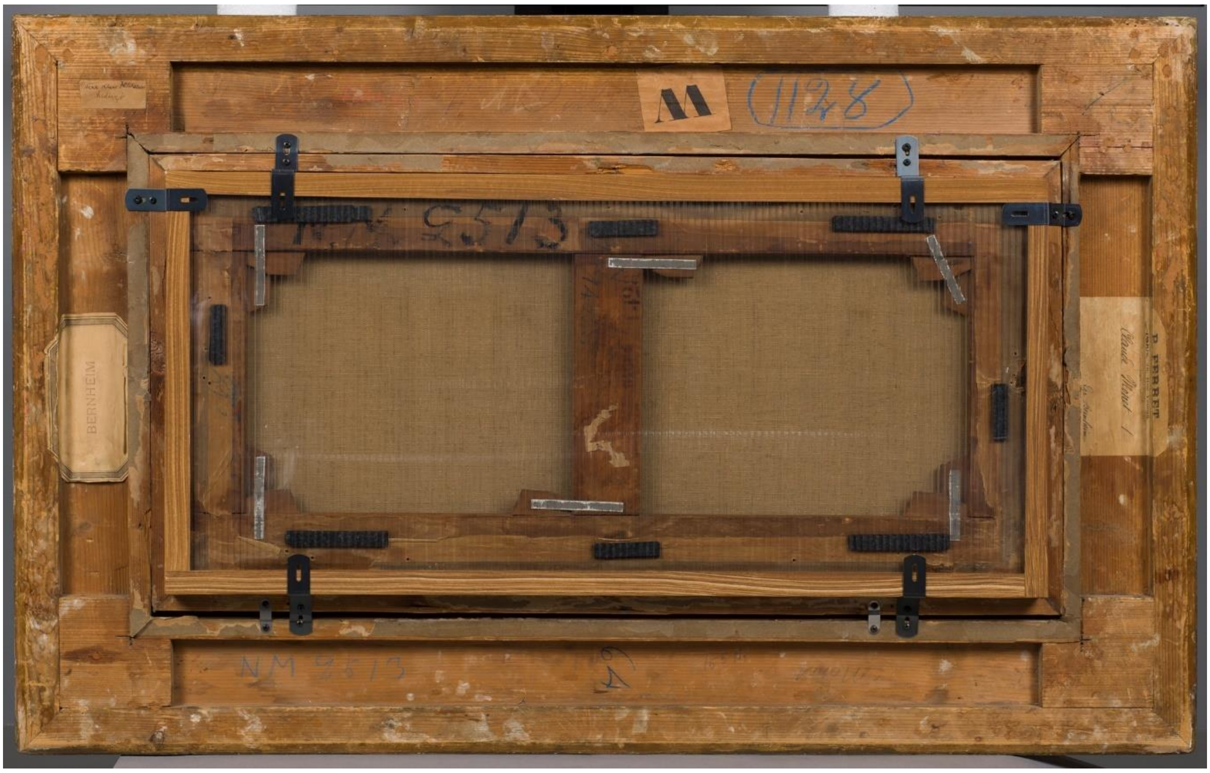

Figure 24: The back of NM 2513 in its microclimate frame with balsa wood box and polycarbonate backing board cushioned with self-adhesive felt. The sides of the box are sealed with painted aluminium tape and the box is held in place with fixing plates. Photo: Anna Danielsson/Nationalmuseum.

4. DISCUSSION AND CONCLUSION

Design and materials

Although most case studies and designs of microclimate frames are for panel paintings, canvas paintings can benefit from this type of protection too. There is not much difference in design for the different painting substrates, except that panel paintings sometimes need a profiled slip/spacers because of deformations. Earlier microclimate boxes were individually designed and custom made for extremely sensitive panel paintings, and could be very expensive to make. Today more or less the same model is used for many paintings in preparations for travelling exhibits and loans. This has allowed for more paintings to be framed, including canvas paintings. The microclimate frames of today are quite inexpensive and easy to make. Sometimes monitoring and following up pollutant levels and climate inside the frames is suggested, but this is of course most of the time not practical or even possible. It is, however, good to do test measurements on a case prototype if the same design is used in many cases.

The term microclimate frame typically refers to sealed frames, but a simple backboard will also provide the painting with a protective microclimate. Adding glazing will further stabilize the microclimate, but allowing around 1 air exchange per hour or more (Hackney 2020). In a small air-volume such as a microclimate frame there is usually no need for added buffers, as the absorbent materials inside the case will be buffering enough. Added silica gel can neutralize short-term fluctuations, but it does not compensate for seasonal changes. Adding silica gel to a case subjected to constantly high or fluctuating temperatures can be harmful for the object as it will release moisture that is absorbed by the silica gel. Silica gel in turn is not affected by temperature (Wadum et al. 1998).

Glass vitrines are also a type of microclimate boxes, and historically microclimate frames have often been of this type. The vitrines house both painting and frame, which can be problematic from a documentation standpoint. More on this below in the ethics section. Shadow boxes are another type of larger microclimate frames that can house both painting and frame, but they have wooden sides and not glazing all around like the vitrines. Microclimate envelopes are enclosures that are tightly packed around the object with a minimal air volume. These are sometimes used as temporary protection while a painting is on loan (Harrison et al. 2018).

At both Nationalmuseum and Gothenburg Museum of Art Tru Vue Optium Museum acrylic is used for glazing and balsa wood battens as spacers. The acrylic glazing has some major advantages over laminated glass, mainly being lighter and more durable. But the risk of bowing during air transport should not be ignored. The glazing need to be at a good distance from the painting, especially for larger paintings. In this regard laminated glass could be favourable for large paintings, but the increased weight makes big paintings glazed with laminated glass difficult and impractical to handle. Balsa wood was used as both spacers and frame build-up in the example in this text. Using balsa wood as frame build-up is not ideal, as it is a very soft type of wood. The build-up will not be a sturdy continuation of the frame, but rather four walls to house the painting and support the backing board. The painting should ideally not be lay flat on its back, as this would deform the balsa wood build-up. An issue with the aluminium tape is its limited adhesion to wooden surfaces. In some cases the adhesion needs to be strengthened with fish glue. Some sources have mentioned the use of inorganic materials for case construction to avoid organic acid emissions, but the polycarbonate used for backing boards and the acrylic glazing are both considered safe materials in this regard (Erhardt 1991).

Benefits

Relative humidity cycling can cause cracking, flaking, cupping and other types of damage to paintings. Mounting a painting in a microclimate frame will not set it up at a predetermined RH value, but it will retard movements away from the room average and cut the most extreme peaks. Using microclimate frames in locations with constantly high relative humidity is not recommended, although they have been used in such conditions with good results.

The results found in different reports on the use of microclimate frames have been overall very positive. Measurements conducted in 14 locations during the PROPAINT project showed that the relative humidity inside the frames ranged from 38 to 59%, whereas RH in the rooms ranged from 25 to 55%. These numbers show reduced humidity variations of 9%. The average temperature inside the frames was 1˚C less than the average temperature in the outside rooms. Light exposure was also less inside the frames than in the outside rooms (Dahlin et al. 2010). Bosshard (1994) describes the design as so successful that the paintings that were meant to be framed only during an exhibition were kept in their microclimate boxes for six years and counting. While RH in the room fluctuated by 30 %, in the case the fluctuations were only 2% (Bosshard 1994). None of the informants spoken with at Nationalmuseum or Gothenburg Museum of art have reported any negative effect of the enclosures. It is sometimes mentioned that microclimate frames should only be used for shorter periods during travel and exhibitions, not for long-term protection. In reality the paintings are often left in their frames when returning from loan. Long-term storage in microclimate frames has had positive effects on paintings in many cases, for example the J.M.W. Turner painting at the V & A that has been in its frame for over a hundred years.

In addition to protecting paintings from relative humidity fluctuations the frames also protect the enclosed paintings from outside pollutants, such as sulfur and nitrogen gases, and particulate matter. Glazing with UV-protection will provide protection from the most harmful irradiation, but the paintings should still not be subjected to direct sunlight as this can create a greenhouse effect with heightened temperatures inside the enclosure. A backing board attached to the stretcher will provide protection from the negative effects of shock and vibration that a painting can be subjected to during transport. The frames will also protect against pests and different types of vandalism.

Risks

The biggest risk of enclosing paintings is the build-up of volatile organic compounds (VOCs). Hackney has proposed consciously making the frames leaky (Borin 2020), while some other sources consider this not a very effective mitigation method (Dahlin 2010; Dahlin et al. 2013). Padfield writes that the entry of outside pollutants would exceed the rate of generation of internal pollutants (Padfield 1966). However, making the frames completely air-tight requires a lot of effort. The degree of seal used in the example from Nationalmuseum does allow for some air exchange, and at Gothenburg Museum of art the frames are often not sealed at the sides. A noticeable consequence of trapped emissions can be that the glazing becomes hazy on the inside and needs to be cleaned. Other consequences are likely to be more gradual and subtle.

When it comes to avoiding the build-up of VOCs inside the frames it is important to use materials that emit as little harmful compounds as possible. If emitting materials are used for backing boards or other components in the design they can be sealed off with barrier films. It is also extremely important to let any coatings applied dry completely before sealing the frame. Paints, glues, varnishes and other coatings release many volatile organic compounds when fresh. The emissions decrease with drying time and taper off after 20 to 30 days, which is why a drying time of four weeks is recommended before enclosing paintings with freshly applied coatings (Tétreault 2017). Some solvents, such as aromatic compounds used in MS2A varnishes, could be trapped in the varnish for a long time, even two years after their preparation, eventually harming the paint layers (Dahlin 2010). But even when fresh coatings are avoided the objects themselves can emit harmful compounds such as organic acids. This is a problem that still needs to be solved.

Ethics and Aesthetics

As was mentioned in chapter 1, microclimate frames both do and do not fall into the category of preventive conservation according to the ICOM-CC definition (ICOM-CC 2021). While the frames modify the environment for the paintings, they also interfere with the structures of the frames and modify the appearance of both painting and frame. It is now being recognized that frames too are valuable museum objects in their own rights, not just containers for paintings. There is an ethical question of how much to do to the frames in order to keep paintings safe. For example the use of glues and tapes that are hard to remove directly on the frames can be questioned. Fastening things to the frames cannot be avoided altogether, but it might be a good idea to avoid it whenever possible. This of course is an issue for all paintings in frames, not just the ones being mounted in microclimate frames, as frames need attached hanging systems and fixing plates to hold the paintings in place for the works to be allowed to be exhibited. These fixing systems have typically been changed multiple times over the years and are not considered to be an important part of the original object. In some ways the picture frame takes on the role of both object of art and of object with a clear function. Caple (2000) suggests extending the category of working objects to include objects that perform their intended function (Caple 2000, p. 144). Frames are rarely seen exhibited on their own, and although they are museum objects in their own right, their main function is to keep paintings safe and heighten their aesthetic qualities. Because of this, replacing lost parts of frames or modifying them in other ways when they do not meet this function is seen as necessary, but there must be a balance between treating the frames as the artworks that they are and modifying them in order for them to fulfill their function. Microclimate frames should be constructed in a way that does not require original parts of frames to be substituted for new, and ideally as little additional material as possible should be added to the original.

An important issue to be considered with microclimate frames is the aesthetic values of both painting and frame. Even when the microclimate boxes are fitted inside the frames there are a few aspects that could affect the viewer's experience of the painting. First, the spacers used to separate the glazing from the artwork are visible in most cases. Oftentimes they are barely noticeable if toned in properly and nicely aligned with the rabbet. But sometimes the rabbet is uneven, the frame corners are anything but 90˚ and the spacers will look different on each side, with wonky corners and uneven sides. The increased gap between painting and frame could also compromise the aesthetic unity of the two. The second aesthetic aspect is the build-up on the back of the frame. Sometimes, with aluminium tape or Marvelseal 360, the back of the painting can look a bit messy. Fortunately, the back is rarely seen by museum visitors. Build-ups and sealing tapes that are painted like wood will not be as disturbing if seen from the side. And lastly, perhaps the most important aesthetic factor to consider, is whether or not the glazing takes away from the experience of the artwork. The new, antireflection glazing options are barely visible when viewed from the right angle but noticing different textures in the paint could still be more difficult. Dust or other small particles that get trapped in the frame and fingerprints on the inside of the glazing can also be very disturbing and hard to remove once the frame is sealed. Care must be taken to clean the frame properly, avoid clothes that shed a lot of fibers while building the box, and keep the protective plastic on the glazing as long as possible. Generally, vitrines create more of a barrier between object and viewer than a microclimate frame housed within the picture frame does. More or less all artworks on paper are glazed, and this is generally not considered disturbing. There is, however, a difference between a dark surface and a light surface, where glazing on a dark painting will be more noticeable.

Another ethical issue is the documentary value of both painting and frame, and how this value can be compromised by constructing a microclimate frame. There is often a lot of information found on the backs of paintings and frames regarding the objects' provenience. Some of this information might be covered when the painting is sealed in a microclimate box, but most of the frame will be visible. In many cases good photographs and documentation might be enough for a researcher studying a painting's provenance. When it is not the seals on the frames can be cut open and resealed after the research is done. In some ways, this can also prevent unnecessary handling. Transparent backing boards have the advantage of allowing inspection of the back, although some parts of it might be out of sight. Vitrines are another issue, because they cover all of the backs of both painting and frame, and makes inspection impossible without removing the objects from the case.

Current and future trends

When it comes to materials and construction of microclimate frames the properties of different glazing options will continue to improve and the acrylic options are likely to become more affordable. The use of pollutant scavengers such as activated charcoal cloth in microclimate frames will probably be further investigated and implemented. Products especially designed for museum purposes have shown no advantages over activated charcoal materials (Dahlin et al. 2013). Activated charcoal cloth is found to be the best performing and the easiest to use of the activated charcoal products (Grøntoft et al. 2015). More information is needed on how to use these in proximity to artworks, and any possible risks associated with these products. Tests during the MEMORI project indicated that secondary or degradation products were generated (Dahlin et al. 2013).

Sustainability issues are being discussed more and more, and museums worldwide start to relax their level of climate control to reduce their carbon footprint. The increased pressure on museums to lower their use of energy has more been brought up as an argument for the use of microclimate frames in more recent articles (Schiewick 2020; Verticchio et al. 2019; Dahlin 2013). It is stated in the IIC and ICOM-CC 2014 Declaration on environmental guidelines that "Care of collections should be achieved in a way that does not assume air conditioning (HVAC). Passive methods, simple technology that is easy to maintain, air circulation, and lower energy solutions should be considered." (Bickersteth 2016). One such passive method is the use of separate microclimates for especially vulnerable objects. Art on paper, as well as many panel paintings, are framed today. This could be extended to include more paintings on canvas as well. Glue-lined paintings, or paintings with reoccurring flaking, are good candidates. In addition to individual enclosures, microclimates in the form of smaller rooms with stricter climate control are another solution that is used for sensitive objects that cannot be placed in individual enclosures. When the most vulnerable objects are placed under more controlled conditions, the general exhibition rooms can be allowed to maintain more relaxed climate conditions.

Bickersteth calls for separate environmental guidelines for objects within a permanent exhibition and objects on loan. For loans the guidelines should enable museums to move objects to different locations minimizing periods of acclimatization, and for permanent display and storage the goal should be to provide environmental conditions closer to the local climate to reduce energy use (Bickersteth 2014). When going on loan, paintings are kept in their packing cases for some time to acclimatise when arriving at a new location. A microclimate frame will essentially prolong acclimatisation to the new environment.

But constant travelling is still a risk to paintings. As Caple has pointed out, the level of use of different objects can vary tremendously. Some objects are constantly requested for display or loan, and others just sit in storage (Caple 2000). For the paintings that travel a lot some extra protection might be needed, regardless of their condition. While providing much needed revenue for loaning and receiving institutions, constant travelling exhibitions have a major environmental impact. Perhaps in the future there will be a change to the constant travelling of some paintings and the blockbuster exhibition concept. In an article for Vastari, Bernadine Bröcker point at a few trends in travelling exhibitions that have emerged during the pandemic and that she sees developing in the future, including prolonged loans and exhibitions, digital solutions that audiences would be willing to pay for, as well as digital couriers (Bröcker 2020).

5. SUMMARY

This project deals with the use of microclimate frames for paintings on canvas. A microclimate frame is typically an enclosure for a painting housed within the picture frame, with glazing at the front and a backing board behind the painting. The whole thing is sealed to create a stable microclimate. The aim of this project is to identify trends in microclimate framing of paintings, and the objectives to describe framing practices at some large Swedish art museums and to describe the process of microclimate framing in more detail with a focus on materials.

The research questions of the project are

1. Why are microclimate frames used for canvas paintings?

2. When and how are microclimate frames used for canvas paintings?

3. What are the benefits and potential risks of using microclimate frames for canvas paintings?

The study is conducted mainly as a literature review on topics related to microclimate frames. The text is structured in two main parts, the first one dealing with the questions why and also to some extent when microclimate frames are used. The ten agents of deterioration are used as a framework in this chapter to determine what sort of risks paintings on canvas are subjected to and how microclimate frames are beneficial for reducing some of these risks.

In the second main part of the study the questions when and how microclimate frames are used are investigated. The focus is on different designs and their performances, as well as a short historical overview to describe how the frames have developed over time. In this chapter more information on framing practices at Nationalmuseum and Gothenburg Museum of art is provided. The case study on a microclimate frame for a glue-lined Monet painting aims to show how microclimate framing can be done in practice.

Paintings are sensitive to fluctuating relative humidity because they are built up in layers that respond to humidity in different ways. Microclimate frames have been shown to have great effects in reducing relative humidity fluctuations around the objects, as well as protecting the paintings from outside pollutants, UV-light, pests and vandalism. They also provide great protection against different forms of physical damage, including protection against shock and vibration during travel. At both Nationalmuseum and Gothenburg Museum of art Optium Tru Vue Museum acrylic is used as glazing and twin wall polycarbonate sheets as backing boards. Paintings are generally mounted in microclimate frames when they are going on loan or into exhibition at a location with uncontrolled climate.

Added buffering materials like silica gel used to be added, but this is rarely done now. As microclimate frames have very small air volumes in relation to how much hygroscopic material is enclosed, they will be self-buffering. The risks are that organic compounds that are emitted from materials inside the frames can be trapped and eventually harm the objects. Different materials have been tested for their mitigation, and activated charcoal cloth could be promising. Making the frames consciously leaky has also been suggested, but this could make the buffering effect less effective and also allow for outside pollutants to enter.

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