Sustainable Film Store Design

Film storage presents a series of challenges which include the need for low temperatures, humidity control and the removal of gases. The aim of this guidance document is to discuss the major principles regarding heat flows, and hence energy use, and not to give direct design guidance. In practice the use of the principles outlined here requires careful consideration of any secondary effects, for example, the potential for moisture to be trapped in the walls. This guide does not consider the fire hazards from film combustion, but it is critical for safe, long-term, storage that the fire hazards need to be considered at all stages of the design.

Heat Flow

The movement of heat within a building is part of 'Building Physics'. In summary, heat will flow only when (a) there is a temperature difference between the building and the outside world; and (b) there is a path for the heat to flow along. Otherwise the building will remain at the same temperature unless there is a source of heat within the building. In the following we will examine each these and the problems and opportunities they present.

Sustainability

Sustainability can mean many things, including having the resources to fund the store into the future, but here we will concentrate on environmental sustainability, particularly energy use. The evidence is that if you want a low energy building, then it is helpful to define this quantitatively in terms of kWh/m^2 of floor area, or perhaps the annual energy bill, rather just specifying a "low energy" building.

Environmental conditions

For film, in general, the lower the temperature the better, with relative humidity in the 30-50 % range. In practice, stable film will have an acceptable life expectancy (>100 years) at temperatures below 10 ˚C; less stable film requires lower temperatures or the life expectancy will be compromised. The decomposition of film accelerates as it proceeds, so more degraded film requires ever more stringent conditions to slow its degradation. FIAF 'ideal storage' recommendations for colour and degrading film are for as low a temperature as feasible, typically: -5 ˚C, 20 to 50 %RH for 'open' storage or -20 ˚C for encapsulated film.

However given their budgetary constraints, archives have to be able to balance the feasibility of maintaining any particular storage conditions against the life expectancy of the film in those conditions. It is worth noting that film reels stored in film cans act as thermal and moisture buffers, and film is resilient to thermal shock. Therefore, conditions in the film store can fluctuate to some extent with little effect on the film. However, the mean temperature needs to remain low.

One aspect of the requirements for long-term storage of film, especially in hot countries, is that the recurrent costs of running the necessary plant is likely to be very high unless good design principles are followed and high building performance standards are met by the construction team. Higher standards will have an impact on the capital cost of building the store; however, because the running costs of a low temperature store are likely to be much higher than a normal building (quite possibly three-times that of a building chilled to 20 ˚C), this expenditure is likely to be cost effective. In essence the pay-back period will be much shorter than on normal projects.

Ground temperature

In countries which have large daily or seasonal changes in temperature, accessing this ground temperature will be highly beneficial. Figure 1 shows the typical temperature over a year in northern Jordan. It also shows the temperature of the ground 5m below the surface. It is the clear that the ground suffers none of the daily peaks that would imply a large daily peak conditioning load for a building in contact with the air. In general, the ground 5m below the surface will be at a temperature equivalent to the annual mean air temperature of the location. (The exception would be if we dig down far enough to access the heat from geothermal energy, which in a few places such as Iceland can be quite close to the surface, but is normally hundreds of metres down.)

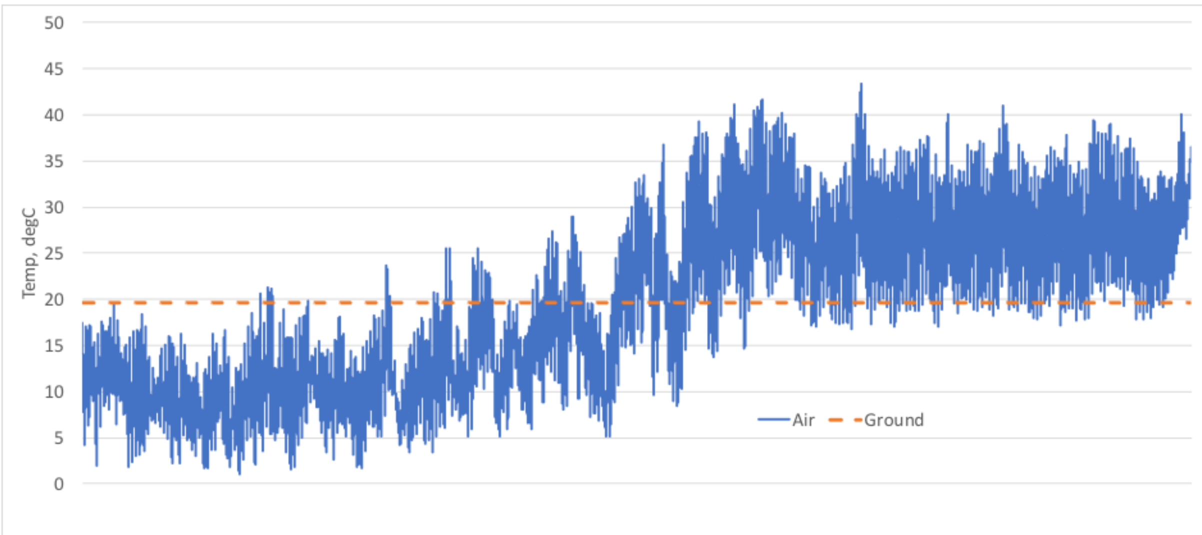

Figure 1. Annual air and ground temperature in northern Jordan.

Although it might not be feasible to reach 5m depth, the ground temperature might be accessed by burying part of the building in a hill or putting the film store in the basement (after considering the dangers of fire to the rest of the building). In fact any depth will help: even just being in contact will the ground rather than being on a higher storey will be a benefit, though to a lesser extent. Doing so will mean that the size of the chillers and other components can be reduced, as the peak load will be lower, thereby saving on capital expenditure. The ground temperature can also be of use for pre-conditioning the incoming air, for example by running the air through a series of pipes under the land surrounding the building.

The size of the benefit of the approach will depend on the location. In somewhere like Bangkok, the annual and daily temperature fluctuates less, and the approach will be less beneficial. There are other considerations too: the water table might make it impossible to build below the surface; the construction industry might not have the experience; the capital budget might be more important than the running costs.

The use of thermal mass

Traditional heavyweight buildings have much the same effect as accessing the ground temperature: they smooth out the fluctuations greatly reducing peak loads and thereby saving on plant size and cost. Concrete block or stone provide this *thermal mass*, but it needs to be remembered that any insulation needs to be placed on the outside of the mass, not the inside if this mass is to be useful. Insulating on the inside surface of a block wall cuts the room off from the thermal mass. If an old building is being renovated and insulation added to the inside, then if the location has a large diurnal or seasonal swing in temperature and chilling is not being used, it is worth considering the addition of non-structural concrete block wall between the insulation and the room.

As in the case of accessing the ground temperature, in locations in the tropics where the daily and seasonal temperatures show very little variation, thermal mass is of less benefit.

The air temperature and the main fabric

Without conditioning, the lowest temperature it is possible to achieve in an archive store is the mean annual air temperature of the location. Getting below this temperature requires conditioning, and as the requirements for film storage imply a very low temperature, the potential for large amounts of heat flowing in through the fabric of the building is considerable, particularly in hot countries.

The equation that governs the amount of heat flow, Q, is:

Q = surface area of the building x U-value x temperature difference between inside and outside

where U-value represents the thermal conductivity of the walls, floor, roof, windows.

(Some countries use the term R-value: this is simply the reciprocal of the U-value, i.e. 1/U-value.)

This gives us three variables to try to minimise: reducing the surface area of the building, reducing the thermal conductivity of the walls, floor, roof and windows, and minimising the difference in temperature between the inside and outside. All will all help reduce energy consumption.

As a broad approximation, each 1 ˚C colder you make the inside of the store, the energy use will increase by 6 to 10%. Ultimately, the temperature of the store will be dictated by budgets and the length of time the film is to be preserved for. It is important to consider if the whole store needs to be at the lowest temperature, and if not, to place colder rooms in the core, away from the external walls (with all due respect to fire safety, of course).

Reducing the surface area of the building is mainly a question of shape. Per square metre of floor area, a square building has a smaller surface area than a rectangular one, and much less than a star-shaped one, so a simple form makes a lot of sense. A store which is no larger than necessary will also help to minimise the surface area.

Reducing the thermal conductivity (the U-value) of the fabric is a matter of insulation. The correct installation of the insulation is as important as its thickness. For instance, where insulating panels are installed behind an inner wall, these should be glued to the wall and glued or taped to each other: if gaps are left between the insulation and the inner wall or between any insulation panels, these gaps will act as small chimneys allowing air to flow and largely undermining the purpose of the insulation.

One key consideration is to ensure that moisture (from people etc.) either cannot enter the insulation or if it can, it can get back out. This is outside the scope of this guide, but it must be emphasised that any project must be supported by a moisture expert, otherwise irreversible harm might be done to the fabric of the building.

Regarding the thickness of insulation required, it should be noted that in the case study of a school designed to maintain an internal temperature of 20 ˚C in a temperate climate (see appendix), the EPS (Expanded Polystyrene) insulation was 150mm thick; if mineral wool had been used instead, this would have needed to be around 300mm thick. So it is obvious that where there is a more extreme temperature difference, such as a film store at 5 ˚C in (for example) Sri Lanka, very thick insulation would be required, and the design of the walls would need to be quite different from a normal building.

Thermal bridges

Particularly when using steel or concrete frames, it may be difficult to avoid creating uninsulated paths – thermal bridges – for heat to flow along. These need to be minimised in number and, if possible, additional insulation added to cover them.

Windows

Windows need special consideration. Although the U-value of a wall can be made very low, reducing the U-value of windows is difficult, and even a modern triple glazed window has a U-value ten times that of a well-insulated wall. Windows are also potentially much greater sources of heat through radiation from sunlight. Hence all windows should be removed from the design. If windows are unavoidable, these need at the very least to be shaded from the sun.

Ventilation and infiltration

Ventilation is defined as deliberately and controllably introduced air, needed to maintain air quality (either for humans, or to reduce the concentration of chemicals). *Infiltration* is air ingress that is not planned and is typically due to poor design, construction, or maintenance.

In most film stores with conditioned air, a heat exchanger is used as the air leaves the building to help cool incoming air. Without this heat exchanger, the energy which had been used to cool the outgoing air will be lost because the air entering the building will be at the external air temperature, and hence need more energy to cool it.

There are two important points relating to ventilation:

1. The system should be designed to use the minimal amount of fresh air, but if there is out-gassing from the film, the volume of air needed for ventilation might be considerable even if chemical filtering is used. The air flow requirements for different volumes of film and for films in different stages of decomposition may need careful calculation, for which specialist help may be needed, and the flow rate and temperatures might need to be adjusted whenever the quantity and condition of the film in the store changes. To aid this, chemical monitoring might be needed.
2. Air is surprisingly heavy—1m^2 of air weighs around 1kg. (A way of thinking about this is that the air in a large lightweight carboard box can weigh more than the box). As the specific heat capacity of air (i.e. the energy need to raise 1kg of air by 1 ˚C) is 1kJ/kg compared to water's 4kJ/kg, every cubic metre of air entering the building is the equivalent of placing a quarter of a litre of warm water inside the building and expecting the chilling system to cool it down. In other words, ventilation can have a large energy cost.

Infiltrating air will not be passing through the heat exchanger and so this can also result in a large energy cost. As an illustration, consider what happens if the store door is left open long enough for all the air in the store to be replaced by external air: this will then need to be chilled and the water removed. How much energy is wasted will depend on the size of the store and the conditions but could well be in the region of 7 kWh. To minimise infiltration it is essential to adopt a construction method that is naturally airtight, for example block and full depth wet plaster, rather the block and plasterboard. Particular care will be needed on site to monitor the quality of the construction for both a new-build or the refurbishment of an existing building. Doors will need to be as tight fitting as possible whilst preserving safe access, and lobby areas with inner and outer doors are usually a necessity. It should be noted that double doors which meet in the middle are notorious sources of infiltration.

If the store is intended for nitrate film, extreme care will be need to ensure the ventilation system cannot contribute to the spread of any fire.

Controls

The control of the system needs to be effective to minimise energy use, but also to ensure the required thermal environment is being maintained. There has been a history of poor control systems within the built environment, with one of the biggest issues being a lack of feedback to the occupier and to management. Ideally the system should report temperature and energy use in a way that is seen by as many people as possible, for example a display in the lobby, not just in the facility manager's office.

Systems and plant

The plant used will be dependent on many factors such as budget and the internal-external temperature and humidity difference. Common failings are poorly maintained systems, the degradation of systems over the years, inappropriate or incorrectly sized systems fitted. It is sometimes the case that heating and cooling engineers are paid in proportion to the cost of the equipment fitted, encouraging the installation of more powerful (i.e. more expensive) equipment than is needed. Also, archives may not have experienced staff capable of maintaining and checking that the systems are working correctly and not leaking. Given these issues, it is good sense to build a store which requires the smallest possible system, as this might well produce reasonable conditions even if the plant were to fail, or funds meant it could no longer be run.

Renewables

Careful consideration must be given to how the energy needed to run the building is to be sourced. For the project to be considered sustainable it is likely much will need to come from renewable energy, possibly from mounted renewables such as photovoltaic (PV) panels on the roof. The amount that can be generated in this way will be specific to the location, but factors such as the orientation of the roof will also be important. However, it is unlikely that energy from PV will be sufficient to fully offset the energy use of the building.

Summary

A typical project might adopt the following approach:

1. Assess the film stock in question: the type and condition, whether it is hazardous, the likely degree of outgassing and hence the required ventilation rate and chemical filtering.
2. Decide on the fire strategy after consulting any national legislation.
3. Set the required lifetime for the stock and hence set the design temperature and humidity.
4. If possible, decide on the sustainability standard you wish to match, for example zero energy, or 15kWh/m^2 of floor area (Passivhaus standard), or maybe just an annual running cost (which should be a value rather than just "a low running cost").
5. Use the answer to 4 to get the building engineer to set the required U-values.
6. Use the variation in seasonal or daily temperature to decide if it is worth trying to access the ground temperature or using thermal mass.
7. Design the building with minimal surface area, no windows within the film-store areas, and very low infiltration.
8. Design the renewable energy system.

Appendix: Additional background

Building Physics

The term building physics covers topics such as heat, light, sound and energy within a building. Here we are concerned with the challenges that a low temperature storage facility present and how building physics can help. The central point to understand is that unless a path is given to heat, or heat generated in a space, the space will remain at the same temperature in perpetuity. If the paths heat can travel minimised in number and magnitude, and the generation of heat in the space equally small, it is possible to design buildings that use little, or even no energy for space conditioning. This can be illustrated by the case of be Montgomery School, Exeter, UK. This school has never needed heating as the building is so well insulated and air tight that the heat leaving the building is less than that generated by the pupils, even when there is snow on the ground. Air for ventilation is provided by mechanical ventilation with heat recovery of the outgoing air.

For a film store in most parts of the world, the building will need cooling rather than heating. The second law of thermodynamics says that heat can only flow from a warmer body to a cooler, and the reason we cool a building is to make up for the ingress of heat – stop that ingress and, once the building has been cooled, it will never need cooling again. Recurrent cooling is a sign of unwanted heat flowing into the building.

Sustainability

To an extent, the question of what level of energy use (and hence emissions) is acceptable – Zero? Or just half that of the current film store? – is a moral choice. The answer is likely to be cultural, but also dependent on the message the owner or financier of the project is trying to give. For example, a government might well want a zero-energy building if the building is in the public eye, as a national repository might be. Then the question of how to decide how much insulation etc. is needed is simple: set the energy budget or environmental standard first, and judge the performance of the architects and builders against this. This approach benefits the building operator, who is the one who bears the annual utility costs.

This approach of setting the standard first and judging the delivery team against it should be contrasted with the normal practice of designing the building first, then trying to minimise the energy use. This suffers from three problems: (a) the initial design of the building is likely to be at odds with energy minimisation (for example large solar gains, or a wall design that makes it difficult to increase the amount of insulation), making large energy reductions impossible; (b) as no target was set at the beginning, the design and delivery team cannot be judged by the client; (c) as the neither the design team not the builder are likely to be paying the energy bill, minimisation of the bill is unlikely to be a central focus.

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