Technical Bulletin 29

Canadian Conservation Institute
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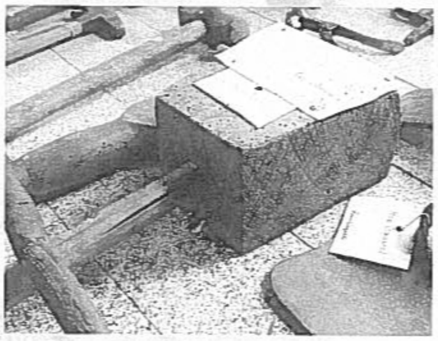
# Combatting Pests of Cultural Property



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Canada

Technical Bulletin No. 29

# Combatting Pests of Cultural Property

by Tom Strang and Rika Kigawa



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## CCI Technical Bulletins

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## Abstract

Pests can be very destructive to both the aesthetic elements and the structural integrity of collections, historic buildings, and objects. Protection against pests requires attention to the collection's environment, containment, discovery of pests, response to pests, and remediation actions. Reducing loss of value over time is the goal of preventive conservation strategies. Integrated pest management (IPM) practices are part of this process. Having a safe work environment and minimizing adverse effects to objects from chemical exposure is a background concern. Effectiveness of any control procedure or treatment can be measured by reducing the extent and repeated incidence of the problem. Basic pests of collections, and a structured approach to pest reduction activities, are presented. A survey method with remediation activities appropriate to pest infestation findings is given to help start an IPM program for a wide range of collections from outdoor installations to state-of-the art preservation facilities.

## Authors

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## Pest Organisms

Pests[1] are living organisms that are able to disfigure, damage, and destroy material culture (Figure 1).

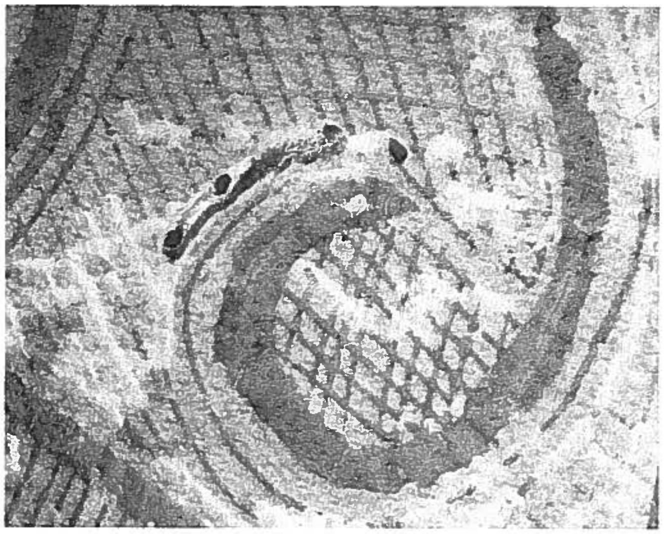


*Figure 1. Dermestid beetle larvae have eaten the decoration on this Naskapi hide mitten because the pigment binder has greatly increased the nutritional value for the larvae.*

As human habitation and agricultural activities have increased, many pests have adapted to and found niches in our buildings and our undertakings. These pests have moved around the world and proliferated through trade and travel.

Microorganisms, insects, and rodents represent the majority of pests affecting cultural heritage. These three subtypes are significant risks in the north-temperate Canadian environment. Other pests, such as roosting birds, molluscs (marine borers), bats, other invasive mammals, lizards, etc., may be significant despoilers in specific locations, but are not as predominant worldwide inside collection spaces.

There are 830 075 described species of insects, 100 800 species of fungi, and 4 496 species of mammals (Lecointre and Le Guyader 2006). While pests are but a fraction of these species, a complete list of pests would be too large for the scope of this document. "Pest" will therefore be defined in general terms by the given subtype accompanied by some common examples; however, the control strategies will not be oversimplified.

1 This definition excludes human activities, which are commonly called vandalism.

### Non-pest organisms

In nature, there are dependencies and competition among organisms. For example, "beneficial" organisms (spiders, centipedes, and parasitic wasps) prey on pests. On close observation, these non-pest organisms will be seen in collections. As with pests, their presence may also be objectionable, causing modest soiling, and indicating that a collection enclosure is not sealed properly.

Non-pest, "non-beneficial" organisms can also be found in collections (e.g. sowbugs, millipedes). They sometimes indicate a pest problem because of their association with certain environmental conditions or their association with the presence of building perforations. Their presence may be objectionable for the reasons stated above. As well, their bodies may provide food for some pest species. Therefore, controlling these organisms is usually undertaken, preferably by keeping them out.

## Pest Subtypes

Pests can be subdivided by biological classification or by the materials they attack. Correctly identifying pests is the first important step in learning the inherent biological limitations of each organism infecting a collection. These limitations are then exploited in order to control them. Be aware that within the pest subtypes, the materials that are attacked will vary. As well, the species within subtypes may have specialized abilities that enable them to exploit or to withstand control measures.

### Microorganisms

Fungi (moulds) and bacteria are numerous and ubiquitous. Mould spores and bacterial spores can be airborne or carried along with other particulates. Bacteria are commonly brought into a collection area by contaminated floodwater or can form in standing water in buildings. Fungal hyphae are the destructive phase of mould. The actions of the hyphae stain and digest objects (Figure 2, p. 2).

For bacteria to survive, water is needed in the form of continuous very high relative humidity (RH) and a high moisture content in the substrate, which includes environments that are under water. Except for spore-forming bacteria (a survival mechanism that greatly enhances the pathogenic nature of tetanus, botulism, anthrax, etc.), most bacterial risk is severely restricted by avoiding constant high humidity or saturation. Many bacteria species are controlled if conditions are drier than 90% RH. All growth is stopped by an RH

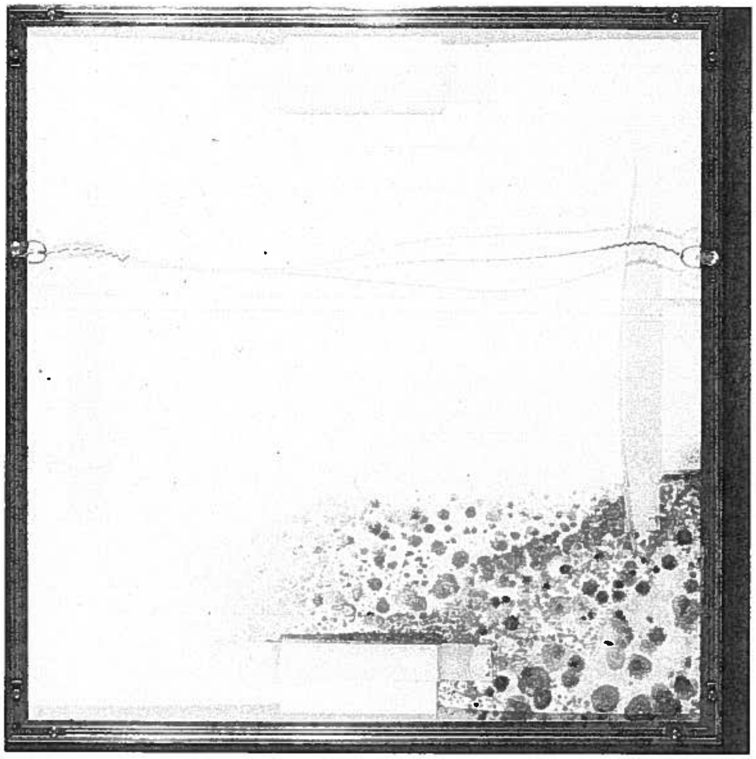


*Figure 2. Mould colonies on the back of a framed print. Their distribution shows the effect of a microclimate created by the varying distance the backing board hung away from a damp wall. Where the gap was wider (top of picture), ventilation could occur by convection; this prevented moisture from building up to levels that allow mould growth. Where the gap was narrow (bottom of picture), the convection of ventilation was restrained; this allowed enough moisture to support mould growth to diffuse to the backing board.*

level below 70%. For microorganisms, RH is usually expressed in terms of water activity (see discussion on mould below). Other factors in the bacteria's environment that can affect the colony's success are temperature, nutritional value, and pH of the substrate. Specific bacterial risks are associated with contamination by soil, dead or infected animals, stagnant water, nutrient-rich fluids, and sewage. These associations can cause such hazards as anthrax, "Legionnaires" disease, botulism, and so forth. However, a return to environmental conditions unfavourable to bacterial growth does not ensure that pathogenic bacteria or their toxins are destroyed; therefore, anyone working with suspect materials must protect themselves properly.

Moulds are less constrained by a lack of water than are bacteria. However, mould growth is limited by the water available in the substrate material. Many mould spores need near-saturation conditions to trigger germination, and continued moisture to survive. Once the hyphae develop, even the most hardy mould species require moisture levels of at least 65% RH to continue to grow. The vegetative hyphae (in the form of fibrous mats and filaments called mycelia) search for nutrients and digest the substrate. Certain wood-destroying fungi can carry water through long hyphal strands, which means growth can be supported far from the sustaining dampness. Fungal spores are produced above the vegetative growth (the mycelial mat) in specialized organs. These spores are easily spread by air currents and through contact with humans and other organisms.

If moisture is supplied by damp air, mould can be marginally viable in nutrient-rich materials stored above 65% RH. Mould growth increases in vigour above 75% RH, and becomes strongly active above 85% RH. Mould growth is ultimately restrained by immersion in water, which limits oxygen availability. Mould growth is also limited by dehumidification, which consequently limits the amount of water that is available for use in the substrate. This limiting condition is reported in food science literature as "water activity" — a numerical value equal to RH expressed as a fraction (e.g. 75% RH = 0.75 $A_w$). In situations where moisture comes from a reservoir of dampness (e.g. soil), the moisture content of the material in contact with this reservoir (e.g. wood sills) has to be reduced to prevent rot. When using moisture meters to determine if organic material is capable of supporting mould growth, the RH limits for growth (say 65%) need to be converted into an equivalent moisture content using a sorption isotherm for that material.

Microorganisms digest, stain, weaken, convey moisture (e.g. "dry rot" fungi), and attract insect pests by modifying and augmenting the nutritive value of an object. Aside from the pathogenic effects of infection, bacteria and fungi pose a health risk to humans simply through high concentrations or chronic exposures that lead to allergic and severe respiratory conditions. Using effective personal protective equipment is strongly advised when working with microorganism contamination (Strang and Dawson 1991a; see Guild and MacDonald 2004 for current recommendations on working with mouldy collections).

## Insects

Insects and other arthropods are the most numerous animal pests. Because of their specialization, small size, mobility, sensory capability, and fecundity, insect pests are a persistent threat to the collections they favour (Figure 3).

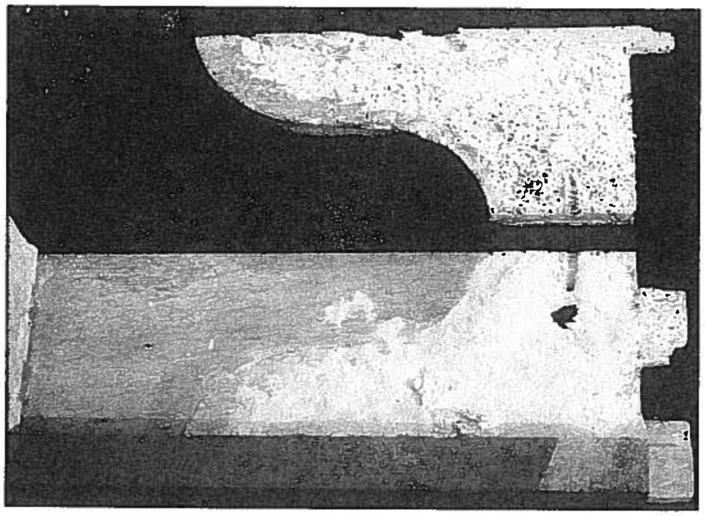


*Figure 3. Anobiid beetle larvae have chewed most of the wood away from this table's leaf support. Very little activity is seen, however, on the exposed varnished surfaces.*

Insects can have very specialized food requirements; therefore, the hazard they pose should be thought of in terms of material type, not object type. Insects are normally present in the natural environment and find their way into collections. Or, they enter collections from infested objects that are sent on loan or are newly acquired, much as insect pests are carried around the world through trade and travel.

Insect life cycles vary. The two common patterns are:

- egg → larval stages → pupae → adult
- egg → nymph stages → adult

Larvae and nymph stages are marked by more or less constant eating and growth. This encourages multiple moults as the insect outgrows its hard integument (outer shell). Adult forms may not eat (e.g. clothes moths), may eat different foods than they do in their larval stage (e.g. dermestids), or be as voracious as larvae are on the object (e.g. *Stegobium*).[2] Pupation may occur away from the food substrate, which decreases the chance the pupa will be preyed upon. Adults may also seek alternative sites to meet mates (e.g. dermestid adults meet on flowers where they also eat the pollen). Insects often rely on pheromone cues to find mates (e.g. clothes moths and wood-boring beetles). Some insects disperse quickly throughout collections, while others tend to stay in one place and reinfest the same materials over subsequent generations. However, the potential to spread is always present.

Insects, and less commonly other arthropods, in their need for food and shelter cause damage ranging from incidental soiling to complete digestion of organic materials. Some insects will also bore into soft plastic foams and materials composed of minerals to lay their eggs or to pupate. Some insects transmit human diseases. The presence of food pathogens, insect body parts, and faecal matter in collections can induce allergic reactions in humans. Therefore, precautions similar to those for handling mouldy material should be used when working around insect-contaminated objects.

## Rodents

Rodents are the most dominant mammalian pest in agriculture and commerce. They are usually present in urban or rural localities. (Alberta is the major exception: its long-running, province-wide rat extermination program has been very successful.) Rats and mice easily climb, burrow, swim, and gnaw. They are also very fecund. Because they are often associated with human food and garbage, they are frequently found in collection buildings. They usually establish home ranges within a 20- to 60-metre radius, but may range even farther.

*Figure 4. Rats have left distinctive grease marks on the walls where they constantly rub as they move around their range. Photo: Department of Integrated Pest Management, University of Aarhus.*

Mice usually establish territories within a 20-metre radius, or even smaller areas inside a building, but can range farther abroad, even up to a couple of kilometres. They breed quickly and, thus, will spread out looking for more resources (food, water, and nesting material). They may find these resources easily available in collection rooms. Rats also live

2 Termites and some wood beetle pests harbour symbiotic microorganisms that help them digest otherwise inedible matter.

in colonies. They live in established burrows outside buildings or in nests inside a building. Because all rodent pest activity is strongly associated with food availability, control activities are often aimed at making these resources unavailable.

Rodents gnaw all the time on non-food items to deliberately wear and sharpen their constantly growing teeth. They cache food for future use; urinate to form trail marks and deposit faeces as they explore; leave grease marks along trails; disrupt material by gathering nest materials; and create shelters in protected locations (Figure 4, p. 3).

Dead rodents, sloughed hair, and faecal matter attract and support keratin- and protein-eating insects, which then can spread into collections. A number of human diseases are transmitted from rodent waste; therefore, using respiratory protection and barrier-protective clothing is advised when cleaning any rodent-infested material.

### Birds and bats

Several species of birds roost or build nests on buildings. Their nests and faeces soil and deface the supporting structure. This detritus supports populations of keratin- and protein-eating insects. Their nests also harbour parasites. Exposure to avian source dusts (created from faeces, feathers, and nesting materials) may enhance the development of bacterial and viral zoonoses (e.g. chlamydiosis in pigeons and poultry) as well as cause chronic allergic responses. These reasons, along with disturbing patrons by defecating in public spaces, are incentives for suppressing birds (most often pigeon flocks). Accumulations of bird guano (e.g. in attic roosts) can pose microbial human health hazards if this dust is inhaled (e.g. histoplasmosis, cryptococcosis); therefore, full respiratory protection, barrier-protective clothing, and post-exit sanitary practices are advised if entering these spaces or removing such wastes (Strang 1991b). Several prevention methods can be used to reduce bird roosting in vulnerable locations (Figure 5).

Bats roost in attic spaces and wall cavities that are open to the outside. They can enter through gaps larger than 5 mm. Their accumulating faeces can raise similar hazards to those of birds. Staff are advised to handle these wastes in an equivalently safe manner. (For a basic guide for bird and bat exclusion, see Strang 1991b; for a guide for personal safety, see Guild and MacDonald 2004.)

## Sensitivities of Collections to Pest Attack

### What pests want

The object stands in for what the pest would normally search for (food, water, or nesting materials) in its natural environment.

Surface effects from infestations range from cobwebs and dried faecal excretions, to urine stains and agglomerations such as bird nests, and mud wasp and paper wasp nests. These surface effects can permanently mar an object's vulnerable finishes or accelerate a microbial attack on an object.

Grazing and gnawing activities are accelerated by surface deposits and salts that attract a pest, or by the pest's need to chew. Pests chew and digest these materials, not the objects per se. Their attraction to particular objects may be further increased by the object's design if it facilitates access (e.g. the rough surface of an exposed end grain that allows the wood borer to lay its eggs) and shelter, or by residues on the surface. Whatever the reason, it is the pest's native ability to recognize and utilize the material that stimulates and sustains pest damage.


*Figure 5. Anti-bird-roosting spikes on this heritage building protect patrons and the structure from soiling.*

In describing the risks, listing some representative object classes will indicate the vulnerability of materials and the possible extent of pest risk. (See Table 1, which uses familiar curatorial categories of materials.)

## Sensitivities to moulds

All organic and inorganic surfaces can be colonized by moulds under the right conditions of high humidity and dispersion of nutrients. Damp cellulosics (paper) and proteinaceous (parchment) materials are the most affected because they are entirely digestible, relatively soft, and can be hard to clean at the porous cellular level where microorganisms contaminate an object (e.g. invasive fungal hyphae, tiny spores with strong pigmentation). Paper and parchment objects often have high information content (text, illustrations, etc.), so the obscuring effects of microorganisms are often gravely disfiguring. Moulds will also grow on inorganic surfaces in the presence of nutrients and moisture. The ability to identify microorganisms and their degree of risk to people and materials requires special equipment and training. Being able to distinguish surface mould from dust and other soiling matter is a useful skill that will help guide preventive conservation decisions.

## Sensitivities to insects

Due to insects' specialization in feeding, burrowing, and breeding activities, there is a wide diversity in a collection's vulnerability to specific insects. However, some insect pests are generalists, and will affect related groups of materials. Table 1 presents a coarse categorization of primary hazards.

Insects are specialized in their feeding habits due to differently adapted mouthparts, digestive systems, and symbionts (e.g. gut-dwelling microorganisms that convert cellulose to usable sugars). For example, different insects are attracted to dry seeds and to starch-adhesive pasted paper. Although both objects are largely starch-based, weevils are more likely to attack dry seeds and silverfish are more likely to attack starch-adhesive pasted paper because of their different mouthpart structures.

Soiling of objects increases their susceptibility to pest attack, in particular silk and cotton fabrics. These fabrics are not usually eaten as food by insects without the presence of added nutritional materials.

See Table 1 for a material's vulnerabilities and the corresponding insect pest that will attack the material. Table 2 (p. 6) describes the insect pests referred to in Table 1.

**Table 1. Materials, objects, and common damaging insect pests**

| Material | Damage to representative objects | Common pests |
|---|---|---|
| Cellulosics: solid masses such as timbers and shelved books | Holes bored in book block and board book covers, wood implements, and furniture. Wood structures bored into are weakened, especially near end grain (joints) of beams, poles, piles, sills, rafters, and flooring. | Structural wood pests, lyctids (hardwood only), anobiids, longhorn beetles, carpenter ants, termites (limited range in southern Ontario and British Columbia). Also, a wide variety of wood-boring insects are found in rotten wood and wood outdoors in damp conditions. |
| Cellulosics: paper surfaces | Grazing to eating book covers, artwork, letters, wallpaper, and insulation. | Silverfish, cockroaches, book lice (psocids). |
| Plant fibres and flower parts, leaves, and bark | Herbarium specimens, baskets, cordage, and coarse-fibre goods. | Cigarette beetle (*Lasioderma serricorne*), drugstore beetle (*Stegobium paniceum*), *Reesa vespulae*, ptinids. |
| Starches | Boring into stored seeds and grains. Consumption of adhesive paste joints. | Weevils, Indian meal moth, cockroaches, silverfish. |
| Keratin: hair, fur, nails, horn, and baleen | Stripping of fur clothing, hair embroidery, quillwork, and natural history specimens. | Clothes moths and dermestids. |
| Collagen: skin, hide, and parchment | Garments, sinew cordage, bags, drumskins, glue joints, and book bindings. | Many dermestids, commonly *Anthrenus* and *Attagenus* species, *Thylodrias contractus*, and ptinids (spider beetles). |
| Mouldy and damp objects | Grazing on micro-moulds found on archival paper, artworks. | Psocids (book lice) and lathrids (plaster beetles). |

### Table 2. Major insect pests and their associated, diagnostic signs

| Common name | Presence indicators and characteristics | Latin name |
|---|---|---|
| Powderpost beetles | Small round holes in wood and floury frass. Lyctids are small brownish adults, attack only hardwoods. Prevalent across Canada and a common problem. | *Lyctus brunneus* and others |
| Furniture beetle<br>Cigarette beetle<br>Drugstore beetle | Small round holes in wood and granular frass. Anobiids are most common in wood objects of European origin, but native species (*Hemicoelus* spp.) can attack structures.<br>*S. paniceum* and *L. serricorne* are severe pests of organics in collections. | *Anobium punctatum, Lasioderma serricorne, Stegobium paniceum* |
| Longhorn beetles<br>Old house borer | Large oval holes and cavities in timbers. Cerambycid spp. are a timber pest in Canada. Most will not reinfest seasoned wood.<br>While introduced species are now damaging hardwood and softwood trees, only *Hylotrupes bajulus* (old house borer) has the potential to be a severe pest in museum collections due to its capacity to reinfest old timber. It is predominantly limited to the eastern United States. | *Hylotrupes bajulus* |
| Wharf borer | Wharf borers have been found in Canadian heritage sites associated with damp timber or wood mill waste. | *Nacerdes melanura* |
| Flathead borer | Large oval holes in timber. Metallic-coloured buprestid borers have emerged from timbers in historic sites and collections, sometimes many years after cutting the timber. They are not likely to reinfest. | *Buprestis aurulenta* |
| Hide beetles<br>Carpet beetles | Brown-banded "furry" larvae and cast skins found on furs, feathers, or roaming on objects, frass piles, and loose hairs in drawer bottoms. Among the most common of collection pests. Dermestids are natural scavengers of nests and dead animals. Adults associated with wildflowers. Natural history museums use colonies of *Dermestes maculatus* to clean specimens. | *Anthrenus verbasci, Thylodrias contractus, Attagenus unicolor, Dermestes maculatus, Anthrenus scrophularia* |
| Webbing clothes moth<br>Casemaking clothes moth | Small, white larvae in webbing or flattened cocoons on surfaces, grazed "channels" on or holes through wool fabric. Common in historic collections and very destructive. Tineid adults are small, whitish moths with fringed wings. Sometimes confused with Indian meal moth infestations (cracked seeds, grains) but *Plodia interpunctella* has coppery "shoulders". | *Tineola bisselliella, Tinea pellionella* |
| Silverfish | Grazed surfaces or ragged holes in paper. Silvery fish-shaped nymphs and adults, *Lepisma* have two sweeping antennae and three trailing hairs. | *Lepisma saccharina* |
| German cockroach | Nymphs and adults are brown with two dark stripes on thorax. *Blattella* are very fecund. They aggregate on spilled foods; starches preferred. Can affect objects made with starch pastes. | *Blatella germanica* |
| Book louse | Tiny, translucent, bulbous abdomens, commonly wingless. Psocids favour dampness, but can roam for a couple of weeks in drier locations. Commonly grazing microbial contaminants on paper, and a warning of damp conditions. | *Liposcelis* spp. |
| Carpenter ant | Large black ants, commonly seen roaming in springtime. *Camponotus* will hollow out rotted trees or timber, ejecting frass that looks like saw shavings. Can be severe pest of timber in historic buildings, fencing, and susceptible trees on grounds. | *Camponotus pennsylvanicus, Camponotus herculeanus, Camponotus modoc* |
| Termites | Subterranean; larvae may build shelter tubes. Adult *Reticulitermes* can be seen flying (as ants do). Unlike ants, termites have a thicker "waist". They are a regional hazard in Canada (southern Ontario, southern British Columbia, southern Manitoba). While not yet destructive to heritage in Canada, a potential hazard where present. | *Reticulitermes flavipes, Reticulitermes hesperus* |

## Sensitivities to rodents

Rodents will damage any material that can be chewed or gathered for nesting, including glass fibre insulation. They can carry noxious material in their mouths without risk of swallowing the material. Any materials that are stored in the path of rodents searching for food will be soiled by urine traces and faecal pellets. Any collection object made of starch, protein, or fat (favourite rodent foods)

### Table 3. Major rodent pests

| Common name | Description | Latin name |
|---|---|---|
| Brown or Norway rat | Omnivorous, 30–45 cm long, brown with light grey belly, blunt nose, short thick ears. | *Rattus norvegicus* |
| Black or roof rat | Omnivorous, approximately 42 cm long, black or brown-grey with lighter belly, pointed nose, thin large ears. | *Rattus rattus* |
| House mouse | Omnivorous, preferring grains, approximately 17.5 cm long, brownish grey with grey belly, pointed nose, large ears. | *Mus musculus* |
| Deer mouse | Prefers seeds and insects, 15–20 cm long, brown with white belly and white on the underside of tail, large protuberant eyes, large round ears. May overwinter in buildings. Main concern is its link to the hantavirus, a health hazard, transmitted through faecal material and saliva. | *Peromyscus maniculatus* |

will be consumed or damaged and soiled or removed to another location. Besides creating larders, rodents will also use some areas as common defecation areas — a behaviour that intensifies damage if it happens to be on or within an object. Table 3 lists major rodent pests.

### Sensitivities to birds and bats

This group of pests is more harmful to heritage structures and less harmful to collection objects. Unrestrained nesting activity introduces soiling, insect pests, dead bodies, and smells that are at least annoying and, at most, health hazards.

Only 3 of the 19 Canadian bat species habitually roost in buildings: little brown bat; big brown bat; and Yuma bat (Strang and Dawson 1991b). Likewise, only a few bird species will cause significant problems: rock dove; house sparrow; starling; and some swallow species (Strang and Dawson 1991b).

## Control Activities

The impact of pests can be controlled. It takes basic, but prompt, attention to maintenance and effective sanitation practices to prevent pest access and their spread in collection spaces. Systematic detection programs catch problems early and influence appropriately scaled responses to limit pest damage and remove the offending organism.

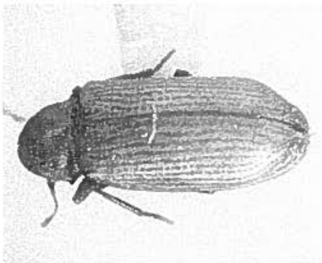
Specific action to prevent pest damage can often be used against many pest types. Common situations and preventive actions in the following tables are coded to the specific pest subtype using the following symbols:

- Microorganism 
- Rodent 
- Insect 
- Bird and bat 

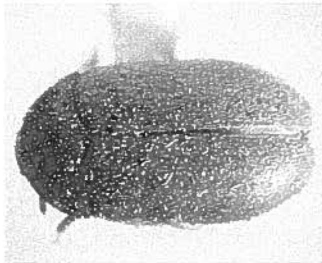
### Avoid

Avoid, remove, or mitigate the effect of pest attractors to deny them necessary life support. While collection objects are often made of materials inherently attractive to pests, the integrated pest management (IPM) goal is to ensure that the object's storage and display surroundings do not support pests (Figure 6). See Table 4 (p. 9) for details.

*Figure 6. In this small, cluttered, poorly organized museum storeroom, it is difficult to do any IPM or other tasks.*

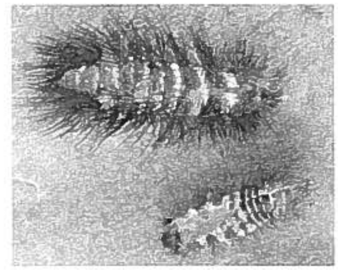


*Anobium punctatum* (furniture beetle), adult.

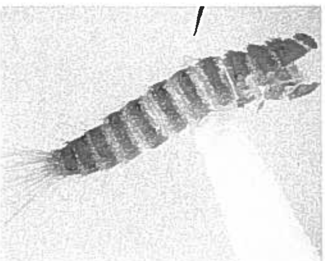


*Stegobium paniceum* (drugstore beetle), adult.

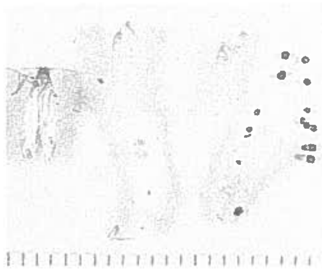
*Anthrenus scrophularia* (common carpet beetle), adult.



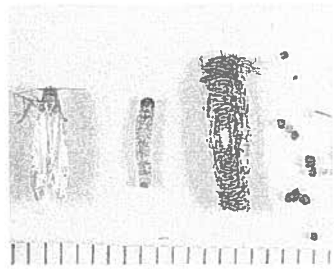
*Anthrenus scrophularia*, larval cast.



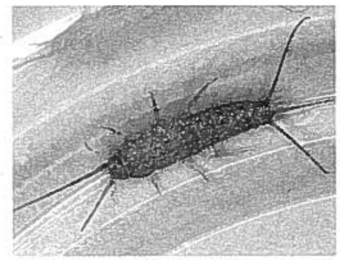
*Attagenus* spp., larval cast.



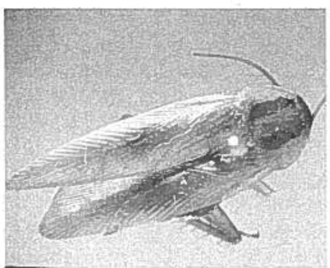
*Tineola bisselliella* (webbing clothes moth), stages and frass.



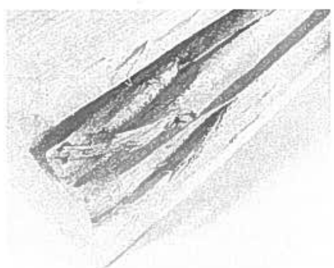
*Tinea pellionella* (casemaking clothes moth), stages.



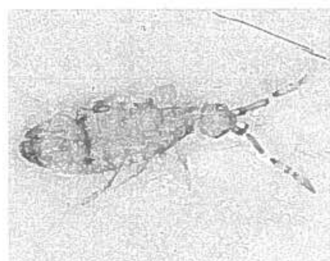
*Lepisma saccharina* (silverfish).



*Blatella germanica* (German cockroach).



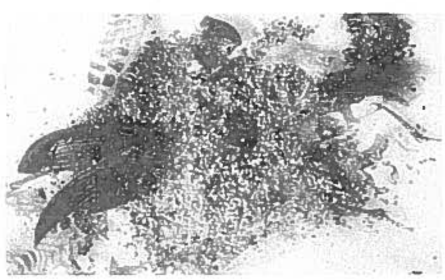
*Camponotus* spp. (carpenter ant), and galleries.



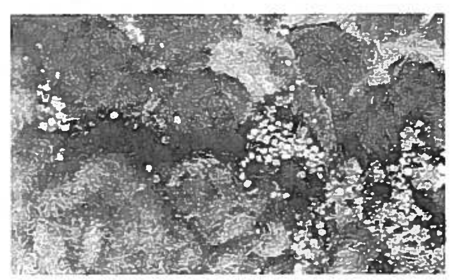
*Liposcelis* spp. (psocid or book louse).

Mouse trapped while damaging attic insulation.

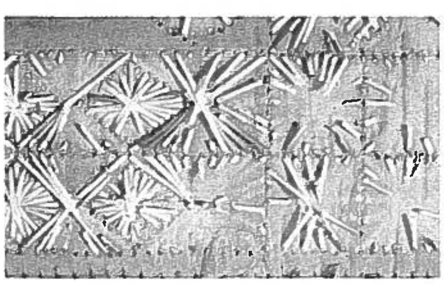
A mud wasp nest disfigures this sculpture.



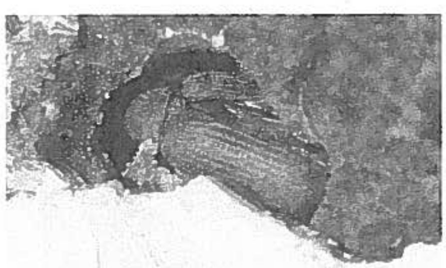
Dermestid larvae eat trapped insect bodies and move on.



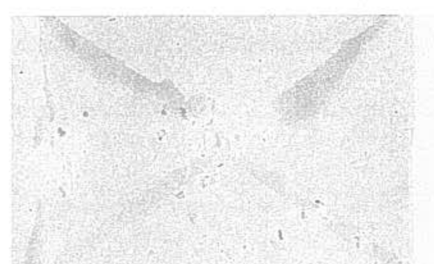
Webbing clothes moth damage to textile.



Clothes moth larvae ate this porcupine quillwork.



This anobiid adult failed to break free of the painted sculpture.



Silverfish grazed on and perforated this envelope.

## Table 4. Actions to avoid pest problems

| Pests | Situation to avoid | Action |
|---|---|---|
| Microorganism, Insect, Rodent, Bird and bat | Spilled or open food (starch, protein, fat) attracts and supports all pest life. | Restrict food areas to places segregated from collections. Encourage the use of tightly sealed food storage containers. Promptly clean up all spills and event areas where food has been served. Flag any foodstuffs (e.g. stuffed animals) in interpretive displays for regular IPM inspections. See Case Study 1 (p. 19). |
| Microorganism, Insect, Rodent, Bird and bat | Sources of moisture support fungi, bacteria, rodents, and some insects. Standing water is a minor attraction for bird pest species. | Reduce standing water where possible. Include water features in a detection regime to identify developing hazards (mould around courtyard fountains, etc.). Inspect sumps and drains in collection storerooms to see if they are supporting silverfish and nuisance pests. Ensure water drains away from all structures to prevent foundation moisture problems. |
| Microorganism, Insect, Rodent | Food, sweat, and blood residues on objects attract pests. | Grazing by insects and gnawing by rodents is increased by residual foodstuff on textiles, baskets, containers, etc. Cleaning these objects will lower their attractiveness to pests and microbial attack in damp conditions. If a residue must be preserved, use blocking strategies to deter pests. |
| Insect, Rodent, Bird and bat | Deliberately feeding animals attracts pest problems. | Unnecessary feeding (e.g. urban pigeons) encourages roosting, soiling, and nesting, and attracts insect pests that feed on bird detritus (e.g. clothes moths, dermestids) to collections. Permanent roosting or nesting activity in or on a structure is high risk for introducing harmful insects. Where feeding programs are part of the interpretation plan, reduce risk by ensuring IPM principles are applied in the area and by properly storing foodstuffs. |
| Microorganism, Insect | Elevated moisture content supports bacteria, mould, and some insect life (silverfish, psocids). | Dehumidify storage to less than a seasonal high of 75% RH for periods lasting less than 2 months, and preferably under 65% RH for year-round storage, which will reduce object moisture content to safe levels, or package vulnerable objects in sealed vapour-barrier containers during the dry season and leave them sealed throughout the damp season (Strang 1998). |
| Microorganism, Insect, Rodent | Clutter implies uninspected areas that possibly harbour rodents and insects. Combined with damp, permanent clutter exacerbates mould problems by providing more surfaces to contaminate in vulnerable places. | Reduce clutter by organizing objects on shelves or clean pallets. Keep clear lines of sight along walls because rodents use room edges as runways. This is also useful for water damage mitigation, intruder detection, and emergency exit. |
| Microorganism, Insect | High humidity conditions (greater than 65% RH). | Microorganisms and some insects require high humidity to go through their life cycle. Reducing humidity year-round to less than 65% RH avoids conditions conducive to bacteria, mould, and some insect proliferation (i.e. psocids). Likewise, maintaining alcohol preservation at 70% (volume percent) ethanol/water and 40% isopropanol/water avoids microbial action deterioration in fluid collections. |
| Insect | Light draws night-flying insects toward and into structures. | Arrange exterior lights to minimize this effect without compromising security. Use light to draw insects away from building openings. Mercury vapour lighting is very attractive to insects. Energy-efficient, high-pressure sodium exterior lighting is less attractive to pests. Reduce use of nighttime interior lighting that is visible to the outside. |
| Insect | Wildflowers are feeding and mating sites for adult dermestids. | Be cautious about bringing in fresh cut wildflowers without removing insect life, or ban the practice. In comparison, cut flowers from reputable florists and cared-for houseplants are a much lower hazard, but must be removed at the first sign of plant pests. |
| Insect | Concentrations of pollen or hair in dust may support insect life. | Overall cleanliness decreases available food for pests, and increases the effectiveness of detection efforts and applied pesticide sprays. Vacuum annually under cabinets. Certain mineral dusts designated as pesticides decrease viability of insects (diatomaceous or synthetic silica powder formulations). |
| Bird and bat | External parts of building structure amenable to nesting and roosting. | Discourage nesting or roosting on a building by using blocking methods such as netting. Providing alternate habitats (bird or bat houses) away from a structure may reduce pressure for finding nesting and roosting spots and aid species at risk. |
| Insect | Wood-boring pests introduced into key structures (building, storage furniture, display, crating). | Use "manufactured" wood products (plywood, laminated beams), and avoid solid wood elements unless they have been kiln dried, which will kill borers (International Standards for Phytosanitary Measures, ISPM 15). Avoid re-using framing timbers unless kilned or treated. |

**Legend:** = Microorganism = Insect = Rodent = Bird and bat

## Block

Segregate valued objects from pests by using pest-resistant materials and practices that will delay or deny access. Use the building as the primary protective barrier. Try to achieve subsequent layers of protection through architectural design that incorporates barriers to pest access, eases inspection and remediation (see Imholte 1999), and provides for tightly constructed specimen cabinets. Effectively blocking pest entry requires attention to all seals and junctions on a structure, and ongoing timely attention to maintenance (Figure 7). Table 5 lists pest-blocking actions.

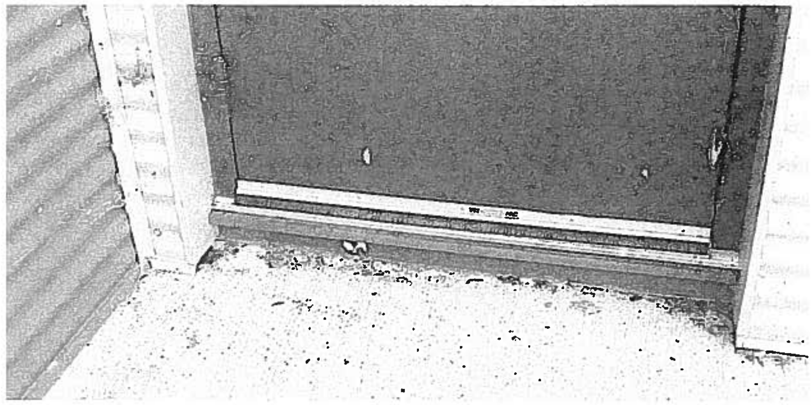


*Figure 7. Effective weatherstripping on an exterior door greatly reduces the ability of pests to enter the structure, despite high insect and spider activity under nighttime lighting. Better cleaning is needed, as seen by the residues near the door.*

### Table 5. Actions that block pest activities

| Pests | Situations requiring blocking | Action |
|---|---|---|
| Microorganism, Insect, Rodent | Health hazards from handling mould, faecal contamination, dead rodent bodies. | Prevent exposure to health problems. Animal faeces and carcasses can present viral and bacterial hazards. Dusts of insect origin are strong causes of allergic reactions (Strang and Dawson 1991a, 1991b). Therefore, wear approved respiratory protection, gloves, and protective or disposable coveralls when dealing with mouldy buildings and objects or insect- or rodent-infested collections. |
| Insect, Rodent | Building vulnerabilities that allow ingress of certain pests. | Repair foundation cracks over 1 mm wide (0.3 mm in termite zones). Seal gaps between continuous sheet flooring and walls. Apply blade seals around opening windows and under doors. Attach wire mesh to exterior vents to restrict animal access (6-mm hardware cloth to restrict mice, 1-mm mesh to restrict most insect pests). |
| Microorganism, Insect, Rodent | Improperly sealed metal or wood cabinets that allow pests to enter. | Use pest-resistant materials (e.g. tough silicone rubbers) to maintain effective door seals. Ensure fixtures do not compromise the barrier due to unsealed perforations (e.g. levelling feet, recessed handles, or vents). Ensure objects are pest-free before enclosing. |
| Microorganism, Insect | Unsealed cardboard boxes containing records or objects. | Archival banker boxes are open to pests due to the handle space and loose-fitting lids. Boxes require taping for complete closure. Objects inside should be sealed in a polyethylene liner for added security in hazardous situations. Cardboard box walls can be penetrated by pests (rodents, some insects), but will protect contents from rodent urine and faeces. Ensure objects are pest-free before enclosing. |
| Microorganism, Insect | Oversized and oddly shaped objects, which need protection. | Use pest-resistant films (rolls of sheet material or pre-made plastic bags): polyethylene is a good barrier material that protects up to 10 years; poly(ethylene terephthalate) such as Melinex or Mylar is a better barrier for multi-decade protection. Bags will protect objects from incidental rodent urine and faeces dropped as they explore, but not against their chewing. Heat seal bags for complete closure, or use a tight, multiple-folded mechanical seal. Tightly gathered closures are insect resistant in the short term. Insect perforation of plastic film depends on the ability of the insect to perforate the plastic as well as on the inherent strength of the plastic. Folds in the plastic will greatly increase the bag's vulnerability to insect perforation because a fold presents places where an insect can grab on more easily and chew. Ensure objects are pest-free before enclosing. Do not place a bagged object where it will be subject to a temperature differential. This creates damp areas and risks mould formation (Strang 2001). |
| Rodent, Bird and bat | Structural features that offer shelter and can be used as roosting and nesting sites. | Cover bird roosting sites with black nylon bird mesh. Block unused chimneys at roof level with sheet metal caps, or install screening on functional chimneys to prevent bird access. Use bird spikes to deter roosting on beams and other structural features. |
| Microorganism, Insect, Rodent | Vials containing small objects. | Screw-top glass vials are resistant to insects as long as the inner seal conforms tightly to the rim. Earliest stage clothes moth larvae can penetrate gaps as small as 0.1 mm. Tight-fitting lids designed for holding fluids are generally secure. |
| Microorganism, Insect, Rodent | Quarantine. | Any effective barrier, from a sealed room to bags, can be used as a bulk quarantine area until an object can be treated to kill pests. Control use of this space so that quarantine is not broken. Combine with timely control methods to protect all uninfested collections. New acquisitions and incoming objects on loan can be hazards in a pest-free storage area. |

**Legend:** = Microorganism = Insect = Rodent = Bird and bat

## Detect

The philosophy behind pest detection is "early warning — easier cure". Accommodate detection methods in storage areas and exhibit designs by incorporating a means of access for the staff and discouraging creation of blind cavities. This is also important for supporting sanitation practices. Both traps and direct inspection can be used effectively to find pest problems (Figure 8, p 12). Encourage as many staff members as possible to regularly check for pests by providing basic IPM information sessions and by creating an easy-to-use pest incident report system. Table 6 lists actions that help detect pests.

Key locations to monitor are:
- collection storage areas
- in and under display cabinets
- food service areas
- mechanical and service rooms
- basements
- all entranceways
- fireplaces

Other locations should be added when a significant pest presence is noticed. See Strang (1996a, 1996b) and Pinniger (2004) for information on detection programs. See the Bibliography for pest identification guides, which will help establish in-house expertise.

**Table 6. Detect pests**

| Pests | Detection methods | Action |
|---|---|---|
| Microorganism, Insect, Rodent, Bird and bat | Identification. | Know your pests! Knowledge guides an appropriate and effective response. To save time and avoid frustration, limit identification information to what is needed (clear recognition of hazard). Learn to discriminate mould from dust, dirt, and stains. Learn to identify your insect pests (Table 2). Maintain a general collection of identified specimens for comparison and training. Acquire guide books and identification keys to help staff identify pests. Learn to identify rodent droppings and how to find rodent urine trails using UV light. Learn to identify grease marks made by rodents and bats that identify common pathways and entrances. A simple but powerful hand lens is an invaluable identification tool. Table 7 lists the necessary equipment for a basic identification kit. |
| Microorganism, Insect, Rodent, Bird and bat | Visual inspection provides detailed knowledge. | Because storage and display containers often hide objects from view, detection of pests is related to the ability to enter a space or open a container. Visual inspection programs ensure that low-use collections remain pest-free. Using white acid-free paper to line drawer bottoms or to line storage shelves greatly enhances the visibility of small insect bodies, clipped hair, and frass. An annual visual inspection coupled with effective responses will reduce or eliminate endemic pest problems. A bright flashlight is an invaluable inspection tool to locate signs of infestation such as frass and webbing. Check windowsills and light fixtures for adult beetles. Prioritize inspection if you are dealing with large numbers of objects. Start with those that contain materials most vulnerable to pests, have high value, and are housed in structures that provide poor protection. |
| Insect, Rodent | Trapping provides information when people cannot see the pest. | Deploy adhesive traps for insects. For rodents, use adhesive, snap (break-back), or cage traps (single or repeating) to discover the presence, the type, possible distribution, and frequency of a pest. Traps are especially useful for confirming rodent presence in large structures. Key locations are near exterior doorways, food preparation and waste areas, sumps for water, mechanical rooms, pipe chases, and along walls in collection storage areas. |
| Insect | Use pheromone lures, food lures, semiochemicals. | Trapping with lures is a way to increase the efficiency of using traps that a pest might only blunder upon. Only a few commercial pheromone lures are available for museum pests, but they are generally effective at drawing in male insects. Food lures and other semiochemicals enhance trap efficiency for insect species that are feeding and mobile (e.g. dermestids, cockroaches). Because pheromones are specific to certain species, there are limits to using lure technology, so ensure the correct lure is used in the recommended manner for the appropriate pest. |
| Microorganism, Insect, Rodent | Records give you greater knowledge of vulnerabilities and costs, and assure corporate memory of IPM issues and treatment. | Establish effective pest logs (see Table 8). Chart progress using simple lists and totals over time. Use maps when an illustration will convince others of recurrent issues and will help better organize the information needed for remediation actions. |

**Legend:** = Microorganism = Insect = Rodent = Bird and bat

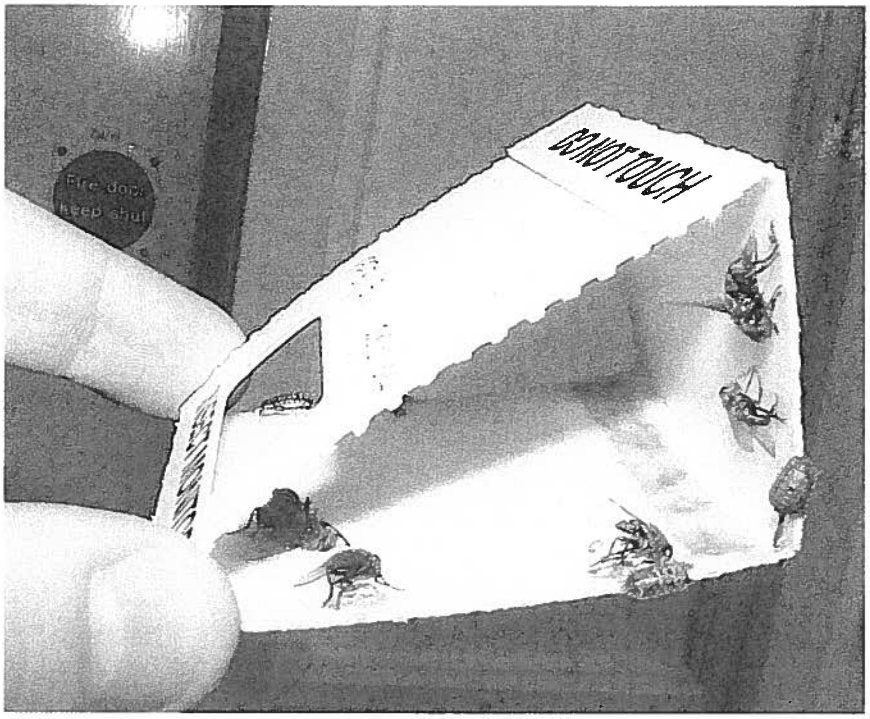



*Figure 8. This adhesive insect trap is designed to fit into the floor–wall junction and intercept moving pests. Periodic inspection and replacement of traps indicate what insect pests are currently in your building and which ones may be affecting your collection.*

To assist in pest detection, assemble the tools listed in Table 7 in a convenient carryall.

Table 8 lists the minimal information needed to create effective trapping and visual inspection records. The purpose for keeping good permanent records of pest activity is to discover and track recurrent problems, or to demonstrate that pest-related problems have been solved by remedial actions. Trap and visual inspections can be recorded in separate ways as long as the information can be coordinated for reporting the results. Paper records can suffice, but electronic versions facilitate working with the data and analysing results with computerized plotting and presentation software.

## Table 7. Equipment for detecting pests

| Detection equipment | Purpose and use |
|---|---|
| Magnifying loupe | Discerns characteristics of small insects and helps distinguish between moulds and dirt. 7–20 x magnification is useful. |
| Powerful flashlight | Illuminates dark areas, objects under loupe. Use raking light to create shadows that will help reveal insect bodies and rodent droppings. |
| Tweezers, spatula | Use to pick up samples without damaging them or exposing yourself to hazards. |
| Small clear containers, bags | Use to store and annotate samples of insects or other signs of infestation for reference, or later to confirm identity. |
| Permanent fine marker | Use to label containers with location, date, object contained, and other useful data. |
| Ultraviolet lamp and UV protective goggles | Use small battery-powered UV light unit to reveal rodent urine trails. Use protective goggles and do not unduly expose skin to UV. |
| Rodent traps | Place in key locations; check frequently for activity. Reset trap after a rodent is captured. |
| Insect traps | Place in key locations, check frequently for activity. Replace regularly after insects are first found on trap (prevents dead insects being used as a food source for dermestid larvae) or when fouled. |
| Identification guides | See the Bibliography for suggested texts, acquire locally useful guides and identification keys, and make your own general collection of identified pest and non-pest species. |

## Table 8. Record keeping to assist IPM activities

| Record field | Purpose |
|---|---|
| Location | Trap locations must be located on a floor plan. Trap locations may be permanent or temporary. Pests are often associated with specific habitats in buildings. Location data help define hot-spots and sources, or show if there are low levels of pests distributed throughout the space.<br>Relate visual inspection locations to cabinet numbers, collection elements, room numbers, windowsills, lighting runs, etc. |
| Trap type | Type of trap, brand, design, baits, etc. can all have a bearing on their effectiveness against different organisms. Recording this information can show trends and guide future trap choices and use. |
| Trap ID | Each trap can be given a marked "serial number" to permanently distinguish it from others in a database. Trap ID is necessary if traps are collected in a sweep, bagged, frozen (to kill insects), and examined later at a convenient time and location. |
| Date trap laid and removed | The period of trapping is a sample in time. This information is essential for presenting a time series showing annual fluctuations or trends. |
| Affected objects | Discovered by visual inspection. Identification of affected objects will guide the delivery of remedial treatment to affected objects. |
| Treatment | Record treatment type, protocol, cost in time and money, and dates. Ensures the problem has been addressed and satisfies conservation ethics. Allows check on effectiveness. |
| Pests | List the pest and non-pest organisms found, and their stage of development (e.g. larvae, adult). Use a level of identification that reveals the risks each pest presents to the collection. This list is useful when proposing effective remedial actions. |
| Count | List the numbers of each pest found, dead or alive. Over time, this information gives a picture of the intensity of a current infestation and the "normal" level of pest activity, once control measures are in place. |
| Comment | Note if the trap has been tampered with, odd occurrences, etc. |
| Observer | Useful in larger organizations to know who did the documentation. |

## Respond

Eliminate pests from structures, objects, and support materials by methodical planning and use of appropriate measures (Figure 9). The priorities are to use methods that are effective, environmentally responsible, and inexpensive. Table 9 (p. 14) lists responses by target pest subtype.

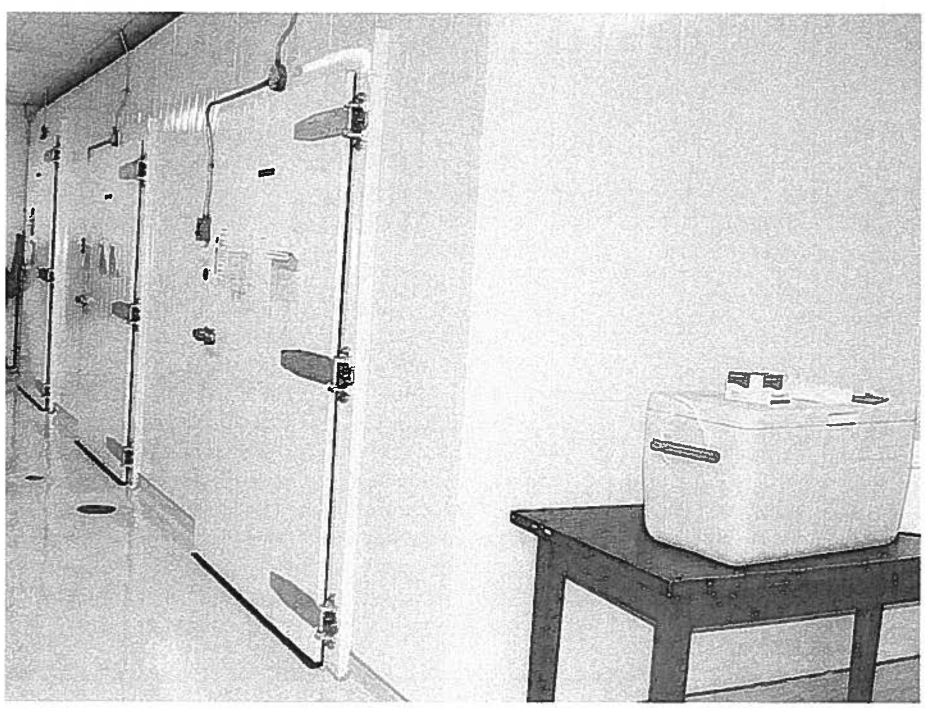


*Figure 9. Household chest freezers and walk-in freezers can be used to disinfest most collection holdings. Other systems can also be scaled from small to large, depending on the situation. Photo: R. Kigawa.*

## Table 9. Response methods to eliminate pests

| Pest | Response methods | Action |
|---|---|---|
| | Sanitation to reduce pest populations. | Aggressive application of **Avoid** and **Block** stages. Physical removal of pests and frass, by picking or brushing by hand, or by vacuuming. Sweeping and mopping are less effective than vacuuming to remove most pests. |
| | Subdivide for protection, quarantine, and treatment. | Seal objects in containers or bags to subdivide problems into manageable units for treatment. |
| | Dehumidify to remove hazard. | Mould growth occurs only in conditions above 65% RH (or equivalent moisture contents for each material). Changing ventilation patterns or adding effective refrigerant or absorbent dehumidification systems to reduce high humidity throughout the year will reduce mould damage. For example, see Case Study 2 (p. 19). |
| | Dehumidify to reduce viability. | Damp-loving insects (e.g. silverfish, psocids, lathrids) require elevated humidity for at least part of their life cycle. Eliminating damp in walls, basements, attics, and service rooms year-round will reduce the numbers of these insects. |
| | Cutting off or restricting ground water. | Water that is taken up into organic structures accelerates fungal attack. Using dampproof layers, including materials to drain water away from site, and elevating structures to break absorbent contact with soil are three strategies that slow fungal attack. |
| | Cool to exterminate or control. | Place affected object in a polyethylene bag or equivalent vapour-barrier container and hold (most conservatively) at -30 to -20°C for 1–2 weeks. -20°C for 1 week kills most insect pests infesting museums (Strang 1992). Lower than -40°C for insect pest control is not necessary and begins to risk thermal stresses on temperature-vulnerable composite objects (e.g. mixed metal–wood veneer). Permanent storage in cold rooms, at less than 10°C, will minimize insect damage risk, but elevate moisture risk and catastrophic mould risk if moisture is not controlled by bagging, mechanical systems, or prompt intervention if the system fails. There are very few objects in general collections that cannot be exposed to this cooling method. See Case Study 3 (p. 20). |
| | Heat to exterminate. | Heat an object at 55°C for 1 to several hours. Exposure is calculated on maximum thickness of the object component or determined by direct measurement of the object. See Strang (1995, 2001) for detailed guidance on issues surrounding heat disinfestation. Enclose the object in a water-resistant bag to prevent desiccation. A wide variety of objects can be safely heat treated. Solar heat can also be harnessed for this purpose (Strang 1995, 2001). See the "Thermal control application guides" section (p. 32). Commercial heating processes balance moisture in the treatment chamber so individual bagging is not required. Wood for export shipments such as pallets and crating is now heat treated to destroy timber pests and marked "HT" (Canadian Food Inspection Agency, ISPM 15). See Case Study 4 (p. 20). |
| | Fumigation to exterminate. | Fumigate objects using carbon dioxide or nitrogen in approved plastic bubbles or fumigation chambers. Nitrogen fumigation by oxygen scavengers can be done in small bags, e.g. using Ageless with heat-sealable, oxygen-barrier plastic films (Maekawa and Elert 2003). Toxic gas fumigants are not desirable because of their environmental and health effects and chemical interaction with objects. Few toxic gas fumigants are available in Canada to use with museum objects or structural fumigation. |
| | Apply fungicide to exterminate. | Wood attacked by fungi can be treated in situ with fungicides. Borates, one of the lowest toxicity systems, continue to penetrate after application, but are washed out by surface water. Other residual fungicides may be coloured, less penetrative, or have restricted use. Surface sterilants, such as dilute sodium hypochlorite bleach (0.5%) or 70% ethanol, can be used on hard surfaces in places that do not directly affect objects. Quaternary ammonium compounds in cleaning solutions can also kill microorganisms but may affect metals, so do not use them directly on objects. The effectiveness of biocidal cleaning solutions depends on contact time. |

**Legend:** = Microorganism = Insect = Rodent = Bird and bat

## Table 9. Response methods to eliminate pests (*cont.*)

| Pest | Response methods | Action |
|---|---|---|
| Insect | Apply pesticide to exterminate. | Pyrethroids (e.g. permethrin), carbamates (e.g. bendiocarb), etc. are generally applied as sprays of liquid chemical mixed with a diluting agent, now commonly water-emulsion-based formulations, but some solvent-based sprays exist. Baseboard, crack and crevice, and cavity sprays are advised. However, direct or incidental spraying of objects is highly discouraged, as it can cause staining as well as mechanical and chemical damage. Pesticides have a range of action speeds, but are not equally effective against all insect pests or life stages because of their differing abilities to be picked up and absorbed or ingested. Pesticides are registered for specific pests and cannot be used outside their defined purpose (Dawson 1992). |
| Insect | Apply desiccant powders to exterminate. | Silica and diatomaceous powders especially formulated for insect control can be blown into problem cavities and dusted under permanent exhibits to eliminate pest shelters. The particulate size is larger than those types of particulates that pose a severe chronic exposure hazard to human respiration; however, protective equipment is necessary when working with these powders. Some powders are co-formulated with "knock down" pesticides. |
| Rodent | Trapping to reduce a rodent population. | Snap traps can be baited and attached to runways. They generally ensure that the rodent is killed quickly. Adhesive traps are efficient and do not suffer from trigger failure. There are some guidelines for humane use, particularly early removal of a rodent caught in a trap, and killing it if it is still alive to reduce its suffering. Repeat action trap cages can remove larger numbers of rodents in high-population densities than can single traps. Live traps will not ensure the rodent is removed permanently from the site because they may re-enter after being released in the open. Sealing the affected space is essential for effectively trapping rodents in order to remove them from a building or they will continue to enter from exterior sources. |
| Rodent | Rodent baits to exterminate. | Toxic baits (e.g. warfarin) are delivered in bait stations to reduce inadvertent poisoning of pets and people. Toxic baits are not advised for use in collections for two reasons. Poisoned rodents may die in building cavities or in collections and attract very destructive insect pests. Rodents can carry poison baits and other items (e.g. glass fibre insulation) with their mouths in a manner that protects them from swallowing the materials. Rodents caching bait outside the bait station creates a potential poisoning hazard to humans. Bait stations are more commonly used outdoors around the periphery of buildings. Caution: rodenticide baits are dyed with warning colours (blue, red, green) commonly seen in food, particularly children's candy. Many rodent bait formulations also support insect pest life, so remove any bait after its utility decreases. |

**Legend:** = Microorganism = Insect = Rodent = Bird and bat

Table 10 (p. 16) compares treatment advantages and disadvantages to help staff choose the best method for their facility's situation.

## Recover

IPM activity should be undertaken by a pest control coordinator who has been given the responsibility and resources to make this improvement in a facility's managerial practice (Figure 10). Without central coordination and continuity, pest problems are exacerbated. Table 11 (p. 17) lists the common situations that occur after a pest attack and the applicable recovery method.

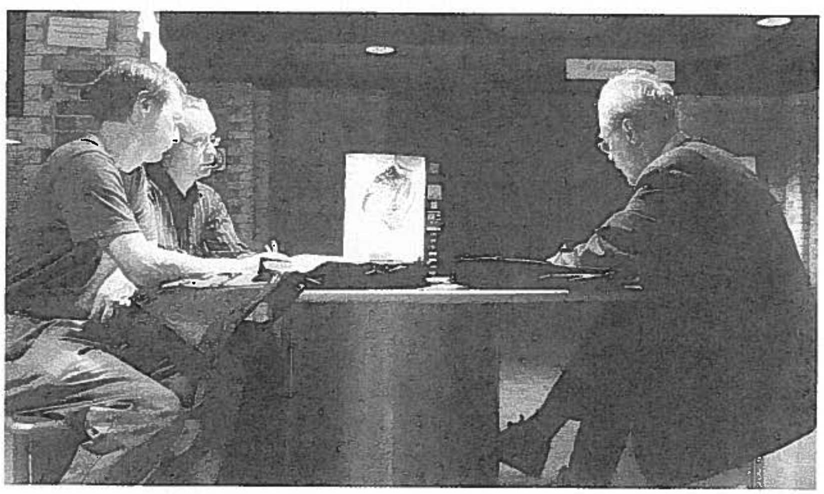


*Figure 10. Museum staff can integrate pest management ideas into everyday operations, or implement a special focus on IPM when serious incidents are discovered. Integrating pest management principles into operations is a balance between over-concern on one hand, and being driven by a pest crisis on the other.*

## Table 10. Comparison of treatment methods

| Treatment for insect pests | Advantages and disadvantages |
|---|---|
| **Heating** to 55–60°C: Exposure time depends primarily on thickness of the object. See IPM application guides (p. 21). Enclose the object in a vapour-barrier bag or equivalent container to contain the pests and eliminate the risk of moisture content change during heating. Space-frames* may need dunnage (natural fibre sheeting) to increase moisture control, or supply moist, conditioned air during the treatment (commonly 15% RH over ambient levels). Heating methods include radiant space heating, forced air, and solar heat (Strang 2001). | **Advantages**: Near universal efficacy against all insects. Universally available technology. Short turnaround time. Wide scale of proven application — from single objects to entire buildings.<br><br>**Disadvantages**: Logistics of enclosure to ensure the necessary vapour barrier exists that will restrict change in moisture content and reduce heat loss, especially when treating large structures. Forced air circulation through air ducts and numerous monitoring points are necessary when treating large structures. |
| **Cooling** to -20°C for 2 weeks or -30°C for a week: Enclose the object in a vapour-barrier bag or equivalent container to contain pests, reduce moisture content change, and eliminate condensation risk on rewarming (Strang 1992, 1997). Ensure that air flows completely around the object in the freezer chamber to prevent relatively warm "thermal bridges" forming. (When objects touch the chamber wall, they become part of the chamber's insulation, which allows heat to conduct into the objects from the outside.) As much as possible, carefully minimize the thickness of stacked, folded, or rolled objects before treatment so the largest surface area is exposed to cold air (e.g. books, carpets). Monitor temperature in the thickest object if possible to ensure the most effective temperature was reached. See IPM application guides (p. 21). | **Advantages**: Widely available technology; household freezers adequate. Winter cold in some locations is sufficient (-25°C or less) provided the object has had a month at human comfort temperatures (i.e. 22°C) before exposure to break insect dormancy. Effective against most museum insect pests that are not preconditioned by cool environments.<br><br>**Disadvantages**: Logistics of enclosing large objects; however, a truck-body refrigeration unit can often be rented to do this. Minimum time in cold temperatures depends much more heavily on species characteristics than does heat treatment, so reducing exposure time is not recommended unless the species and its response are known. |
| **Controlled atmospheres (low $O_2$)**: Expose objects for 1–3 weeks in atmospheres that contain very little oxygen (insects succumb most efficiently to anoxia at less than 0.1%, a common specification for control). Note that wood borers are the most tolerant to anoxia, requiring longer exposures. This fumigation technique uses compressed nitrogen ($N_2$) gas in larger enclosures or oxygen scavengers in smaller volume enclosures. Oxygen barrier films are heat sealable and may only be used once or a few times. Flush out air from anoxic bags with moisture-conditioned nitrogen to conserve the oxygen scavenger. For a detailed application guide, see Maekawa and Elert (2003). | **Advantages**: Anoxia can be performed at room temperature (>20°C) in clear film or metalized film plastic bags. Long-term storage in anoxia bags significantly protects against reinfestation and other deleterious agents such as airborne contaminants, water, humidity swings, etc.<br><br>**Disadvantages**: Effectiveness is greatly reduced by moderately cool temperatures (less than 20°C). Anoxia in bags can be compromised by pinhole leaks or flawed seals. A few colorants are affected by a low-oxygen environment (chemical reduction), but this is mainly observed in long-term storage, not in the time span needed for pest control. |
| **Controlled atmospheres ($CO_2$)**: Expose objects for 1–3 weeks in atmospheres that contain carbon dioxide (60–90% $CO_2$ by volume induces fatal hypercarbia in a useful time period). Wood borers are commonly the most tolerant to hypercarbia, and require longer exposures. Contain $CO_2$ in a rigid enclosure (fumigation chamber) or in a flexible enclosure designed for fumigation with $CO_2$ (Warren 2001). | **Advantages**: Carbon dioxide fumigation works in the presence of any remaining oxygen; therefore, fumigating large objects is generally not compromised by pinhole failures in the container, provided overall gas concentration and circulation are maintained.<br><br>**Disadvantages**: Effectiveness is greatly reduced by moderately cool temperatures (less than 20°C). Carbon dioxide is registered as a fumigant and is an asphyxiant hazard to humans. Proper detectors and procedures are required. Carbon dioxide is a penetrating gas, affects mammalian physiology in low-percentage concentrations, and is easily adsorbed by concrete. Enclosure must be designed specifically for holding $CO_2$. Appropriate life-safety measures must be observed. Longhorn beetles are very tolerant to elevated $CO_2$. |

* Objects whose construction creates a large ratio of open space to their components. When bagged, this results in a large air volume to be buffered.

## Table 11. Actions that assist recovery from pest attack

| Pest | Situation to recover | Action |
|---|---|---|
| Microorganism, Insect, Rodent, Bird and bat | Lack of IPM plan. | Develop an IPM program that addresses the top risks to your facility, ensures subsequent incidents will be detected early, and ensures appropriate detection steps are taken. Continue to integrate pest management practices into the standard operation of a collection's care. With this integration, a pest infestation can be reduced from a crisis or chronic level to a nuisance level. |
| Microorganism, Insect, Rodent, Bird and bat | Sanitation and remedial cleaning after events. | Rodent infestation is strongly related to human food use and waste. As well, other pests are attracted to spilled food and waste. Ensure program staff clean halls immediately after events, including food service, and remove garbage. Budget such clean-up into rental agreements. Monitor and facilitate compliance. |
| Microorganism, Insect, Rodent, Bird and bat | Sanitation and remedial cleaning of infested areas. | Reduce the chance of false warnings of infestation by cleaning up after previous infestations, removing insect bodies, etc. Add relevant information to records about extent of infestation, damaged objects, likely source, and cost of recovery in time and money. |
| Microorganism, Insect, Rodent, Bird and bat | Determine what may have happened in the context of an existing IPM policy. | Determine how a pest entered; how a quarantine procedure failed; if there is a need for more effectively applied suppression methods; and if policies or individual practices need to be changed. |
| Microorganism, Insect, Rodent, Bird and bat | Record the cost and efficiency of all methods used. | During treatment of an infestation, losses to collection, time expenditure, cost of activities, and useful resources should be noted for future reference. In institutions where staff turnover is high, such records are valuable to help plan for future situations. Economic records can be used to underline the importance of ongoing IPM activities and to support budget requests. |

**Legend:** = Microorganism = Insect = Rodent = Bird and bat

## Table 12. Basic control of typical high risks

| Pest | Strategies, activities, and infrastructure |
|---|---|
| Microorganism | Dehumidify to below 75% RH in seasons of warm humid weather (particularly during the summer months), and preferably to below 65% RH for year-round storage. Lower humidity strongly limits growth potential. Lower temperature and low humidity swings further limit growth in other seasons. A refrigeration-based dehumidifier will be adequate if its capacity exceeds or matches the room volume and the room is closed to the outside environment. |
| Insect | Eliminate easy access to all foodstuffs. Use pest-resistant containers to protect vulnerable objects (see the suggestions in the "Block" section on p. 10). Schedule an annual visual inspection for signs of insect activity in stored collections in late summer or autumn. Respond to these findings with control methods such as bagging or using a household chest freezer. Quarantine and possible treatment is advisable for new acquisitions. An annual low-temperature treatment is advised for chronically exposed, high-vulnerability items (e.g. furs on interpretive display in historic houses). |
| Rodent | Eliminate easy access to foodstuffs. Close all exterior gaps, leaving no opening larger than 5 mm. Shield vents with heavy gauge, non-corroding wire mesh. Do not compromise critical ventilation by sealing it with panels, ensure air flow remains adequate. Ensure attic and foundation gaps are also closed to at least 5 mm to prevent climbing or burrowing mammals from entering the building. Late autumn entry into buildings by rodents seeking winter shelter is a common behaviour, so pay attention to signs of rodent activity in this period. Respond with a trapping program combined with improved enclosure of the building, to reduce internal rodent population. |
| Bird and bat | Repair, close, or install wire mesh on all exterior gaps used by bats and birds to enter a building (leave no opening larger than 5 mm, as per rodents). Use bird netting to block access to exterior roosting sites. Block potential nesting sites, but be sensitive to the animal's nesting dates if it is a protected species. Canadian laws protect bats and songbirds from human predation. While local regulations may allow removal from private property, species under pressure benefit from undisturbed breeding seasons, after which enclosure of a nesting space can take place. Likewise, winter hibernation of bats should also not be disturbed; therefore, close the roost's entries during April, or any time from October to November (Strang and Dawson 1991b). |

**Legend:** = Microorganism = Insect = Rodent = Bird and bat

## Control Strategies

The sample strategies for mitigating the effects of the main pest subtypes in Tables 12–14 integrate site, building, fitting, and procedural elements. They focus on key elements in a Canadian context. See Pinniger (2004) and Strang and Kigawa (2006) for guidance in IPM program design. The latter has been adapted to this document as an IPM program guide based on control levels 0–6 (see p. 21).

### Table 13. Intermediate control of typical high and moderate risks

| Pest | Strategies, activities, and infrastructure |
|---|---|
|  | Dehumidify to below 65% RH year-round to eliminate mould and bacterial growth in interior spaces. However, in the north temperate zone, winter humidity levels of heated, occupied buildings will have to be closer to 30% RH to avoid potential mould growth inside insulated wall cavities unless a thoroughly intact vapour barrier is installed. Filtration of fresh air using standard HVAC (MERV 14 air filtration) (Tétreault 2003) reduces spore concentrations. Install water detection alarms to alert staff if water pooling or flooding happens in susceptible zones of a building. |
|  | Use adhesive traps in key locations as a means to conduct a quarterly inspection for insect activity. Conduct an annual visual inspection of collections. Use a household chest freezer as a quarantine treatment method for acquisitions and loans (bag objects). |
|  | Use an interior trapping program combined with effective blocking to detect and control rodents. Avoid using poison bait stations because poisoned rodents and some baits support insect pest life. As well, rodents are able to move poisoned bait to other locations despite careful design of the station. |
|  | Control as described in the basic level recommendations. |

**Legend:**  = Microorganism  = Insect  = Rodent  = Bird and bat

### Table 14. Advanced control of all perceived risks

| Pest | Strategies, activities, and infrastructure |
|---|---|
|  | Use high-efficiency HVAC air filtration (MERV 15 or higher air filtration) (Tétreault 2003) to lower spore concentration and mitigate any building flooding, or HVAC-failure-induced mould risk. |
|  | Hold food waste in a coldroom (e.g. a stipulation in the Quebec building code) or immediately dispose of waste in external compactors.<br>Metal and slab concrete building fabric is designed to control insect entry.<br>Store high-vulnerability, high-value items in hermetic or tightly sealed cabinets or containers such as jars, plastic boxes, or vials. Detect insect action by using adhesive trapping throughout the building, concentrating on high-risk zones. Conduct an annual complete inspection of collections and galleries for insect activity. Plot pest activity by mapping (methods range from paper records to using a Geographic Information System) to ensure control activities cover all sightings.<br>Deliberately seal a collection storeroom to prevent insect entry. Design collection storage areas to be cooled to between 10 and 15°C to limit insect activity if collections are highly vulnerable and open shelving is common (e.g. herbarium, large mammal specimens).<br>Routinely use quarantine accompanied by a response treatment (controlled atmosphere or thermal control method) for all objects acquired, on loan, or showing insect pest activity. Apply control methods to all objects in collections (e.g. from gnats to elephants). In large organizations, penalties for deliberate failure to comply with quarantine regulations may be needed because of the high hazard presented by non-compliance in stored and vulnerable collections or by the cost of remediation. |
|  | Install rodent barrier doors (tight closure, metal fabric). Control exterior conditions, such as rodent-proofed garbage compactors, or good neighbourhood sanitation. Implement a detection program as stated in the basic and intermediate level recommendations. |
|  | Control as stated in the basic level recommendations. |

**Legend:**  = Microorganism  = Insect  = Rodent  = Bird and bat

## Case Study 1: Rodents Living in Large City Gallery

Mice infesting a gallery's "Donor's Room" kitchen, hundreds of feet from any collection storage, near open sculpture galleries and a main atrium, which are food event locations (Figure 11).

Hazards:
- a donor could become ill from contact with a rodent-related, faecal-borne disease
- mice could nest in stored fabric items (e.g. interpretation program costumes, textile arts, object padding) if the colony becomes established

How the mice got there:
- holes through building fabric were larger than 5 mm, due to construction projects that opened up exterior walls
- outside mice colonies feeding on ambient garbage in an adjacent park were attracted to the building
- badly sealed city sewer or steam pipe connections, and gaps under emergency and loading bay doors provided entry routes

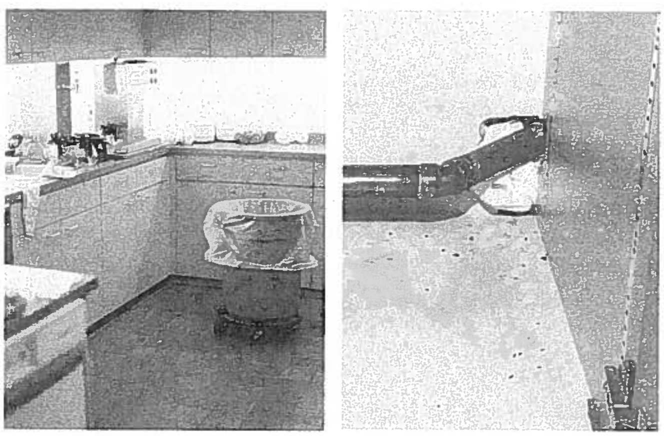


*Figure 11. Kitchens are attractive to rodents, which can enter through a badly fitting pipe chase or by crawling under doors. Most rodent problems are associated with human food in buildings. On the right, mouse faeces can be seen in the cupboard. The access hole has been ineffectively plugged with crumpled paper.*

### Short-term control measures

Loose foodstuffs were cleaned out of cupboards and placed in sealed food containers, and garbage was placed in closed containers. Daily garbage removal was instituted. The access point was located, and an open path through the wall along a sink drainpipe was sealed. Snap traps were set to kill mice in the room and adjacent rooms, which were connected by the pipe chase.

### Long-term control measures

Entering the facility's monthly pest control contractor's records into a graph showed a steady, but constant, accumulation of rodents caught monthly over several years. So either a small number enters frequently and does not survive the trapping program, the internal population has limited mating success, or a sparsely deployed (non-public areas) poison baiting system may be working to limit exponential growth. However, improved exclusionary practices and continued trapping are required to cause the annual catch numbers to drop toward zero.

## Case Study 2: Mould Outbreak in a Rural Museum

Staff of a rural seasonal museum in a former community school building discovered mould and mildew on many objects and wall surfaces while preparing the museum for its spring opening (Figure 12). A persistent vandalism threat had forced them to board up all sash windows and external doors during the previous autumn closing. This act unwittingly changed the ventilation pattern of the building by restricting the air exchange rate. Damp spring weather added considerable moisture through a porous building fabric and the slab-on-grade concrete floor that was built on the site of a former wood-milling operation, which had left a lot of mill waste in the soil. The furnace was set to minimal activity in the core area during winter to prevent the pipes from freezing, leaving former classrooms unheated. Moisture in partially heated buildings moves from warmed areas and accumulates in cool areas. This situation, combined with the elevated internal humidity and warmer daytime temperatures for a couple of months before opening, encouraged mould spores to germinate on objects.

### Short-term control measures

Opening an access door in the central corridor to a well-ventilated attic increased air extraction from

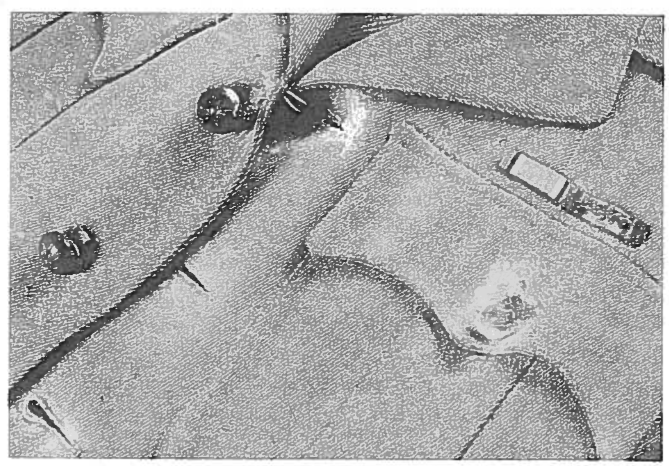


*Figure 12. Mould often becomes visible as whitish spots, but other colours are common. Here mould is growing supported by the nutritional value of the oils on the leather buttons.*

the building and began removing excess moisture. This action of reducing compartmentalization and opening all inner room doors to allow ventilation through to the attic temporarily increased the fire spread hazard.

### Long-term control measures

Use metal grills on windows to ensure security during the closed season (in place of the plywood sheathing previously used). Acquire and run dehumidifiers when the building is closed up (at a cost of buying and running the equipment). Portable dehumidifiers need a connection, such as a simple flexible hose, to a drain for unattended operation. Capacity of the humidifiers must match the enclosed building volume (Strang and Dawson 1991a). Dehumidifiers operate less often during the winter season (their performance is constrained by low temperatures), but are entirely adequate during the critical spring season. Open the building earlier in the season to ensure effective ventilation and to detect problems earlier (increasing staff time on site). Clean objects according to a conservator's recommendation, and hard-surface clean with biocidal detergents.

## Case Study 3: Insects Infest Donation to a Civic Museum

Clothes moths were found infesting a newly acquired uniform collection of hundreds of items (Figure 13). The civic museum has no money or permanent infrastructure for treatment. It would deaccession and dispose of the collection rather than risk spreading an infestation by incorporating these objects into the collection without treating them.

### Short-term control measures

Quarantined the collection by sealing objects in polyethylene garbage bags, leaf bags, or equivalent barrier containers. Clearly labelled the bags with warnings: "PEST QUARANTINED ITEMS — DO NOT DISPOSE" or "MOTH INFESTED — DO NOT OPEN". Also annotated the bags with the responsible person's name, contact information, and date of enclosure. This adequately contained the hazard until treatment could be arranged.

### Long-term control measures

Used outdoor winter conditions to cold-treat the entire collection on the museum rooftop, taking advantage of an elevator shaft superstructure that provided a shaded north exposure. The quarantine-bagged collection was set on tarpaulin-covered pallets that eliminated the possibility of contact with the roof, which could have conducted heat into the objects.

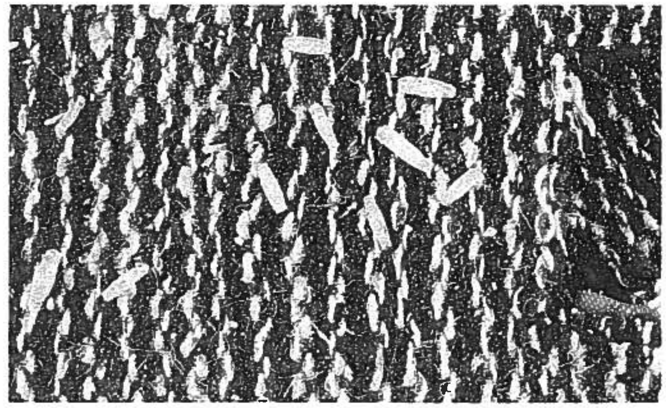


*Figure 13. Casemaking clothes moths can be difficult to see because their cases are made from the material they are eating.*

Wrapped in another tarp for protection against strong wind, the objects were exposed to low temperatures (predicted weather: less than -20°C all day for several days). The collection was exposed for as long as possible: minimum of 3 days for clothes moths, 1 week preferred. The collection was brought indoors, rewarmed overnight, and checked for living insects. Objects were cleaned before they were incorporated into the collection.

As an alternate strategy, infested objects could be treated one-by-one in borrowed space in household freezers while keeping all other objects quarantined in bags to prevent the pest's spread. Sometimes commercial freezer space can be arranged on a gratis basis or a refrigerated truck can be rented. Responding to this volume of infestation could fall under disaster planning and would profit from prior arrangements for services.

## Case Study 4: Wood Borers in Rural Agricultural Museum

A rural agricultural museum's displayed wooden farm machinery and tool collections were severely affected by widespread lyctid wood borers. A local pest control company wanted $300 to look at the problem — money the museum did not have.

### Short-term control measures

Consulting with the Canadian Conservation Institute (CCI), the provincial conservation advisor oversaw the construction of a safe and effective heat disinfestation chamber using volunteered professional services at the museum (Figure 14). Donated materials and air heating equipment were assembled on site. Staff ran several loads of mixed large and small items through the system, one load per day for about 7 hours under constant surveillance. The moisture balance was maintained by the high volume of material self-buffering the contents in the sealed chamber (Strang 2001).

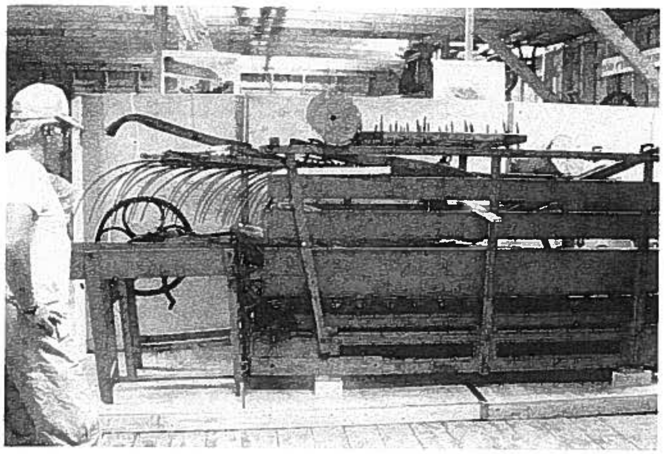


*Figure 14. Objects inside an insulated plywood box that was heated with air and kept between 55 and 60°C until the thickest pieces were heated through. This treatment kills all insect life.*

**Long-term control measures**

Because lyctid wood borers are found in the surrounding region and are associated with dead timber, any further pest activity in subsequent years should be noted immediately and the affected pieces put through low-temperature control or an in situ heat treatment. The museum and the objects should be thoroughly cleaned regularly to see if any insect frass piles are forming. Structural inspection of the building should be done to ensure that any hardwood elements are not affected by insect pests.

## Application Guides

The following application guides are included to help an institution create a first-time IPM program. These guides were designed to be adaptable to a wide variety of situations. Specific pest eradication procedure guides are also available that demonstrate how to simply and correctly follow the various steps.

### Designing an IPM program

This section outlines a basic IPM program. Each table describes a recognizable situation accompanied by IPM recommendations. It can be used to make a rapid survey of a current state and to note items to incorporate into a collection's IPM plan.

### *Levels 0–6. Doing an IPM survey to create a plan of action*

Photocopy the tables so you can mark them up. Determine the nearest level to your situation by matching it to the table's headline description. Read the left column headings of Site, Building, Portable Fittings, and Procedure to see if these descriptions are roughly applicable to your situation. Use a highlighter to mark features that are present in your situation (left-side column). If the terms in the table matching your situation (level) are not applicable, search through adjacent tables to find more appropriate terms to capture the breadth of the situation across your holdings and highlight them. The actions in the right-hand column (Plan B), which are listed near the items you highlighted, are a guide to reasonable activities or modifications that will help ensure a better degree of protection.

One response to pest problems would be to move the collection from its existing level of enclosure to a higher level. Often this is an institution's ideal "Plan A" because it solves many problems in collection care, exhibition, etc. There are degrees of a "Plan A" response. A building upgrade providing new or additional collection storage is a much costlier proposition than a simpler "Plan A" response of moving wood wagons from field display to a place underneath an existing shed roof. Both would provide benefits to long-term preservation from biological and other deterioration mechanisms, but would have different residual vulnerabilities.

The Plan B column was created to show how one can fight back against pests in the given situation if a "Plan A" solution must wait or cannot be done. Using the suggestions given under Plan B, determine if the described activities are being performed, or if the suggested modifications are present in your facility. The Plan B columns were designed to include remedial suggestions where they would most likely be effective and not cause undue effort at that level.

The prognosis and expected deterioration are given as examples of what the uncontrolled situation might result in and the changes that might result from an IPM program or pest control treatments.

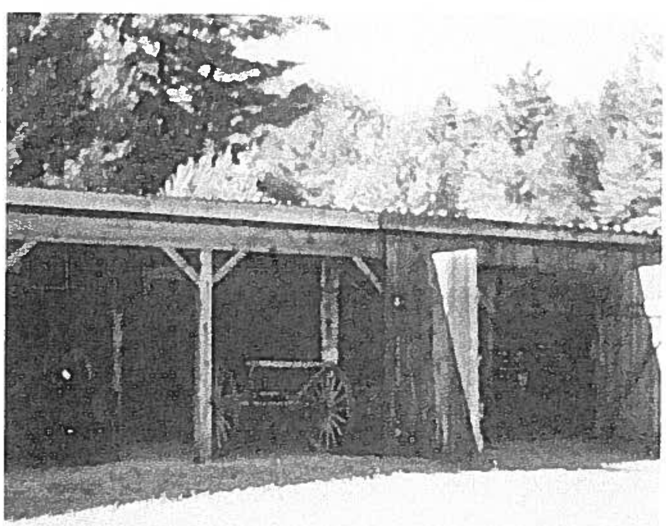
For a full description of the approach and rationale behind these tables, see Strang and Kigawa (2006).

### *Progressive scales of IPM components*

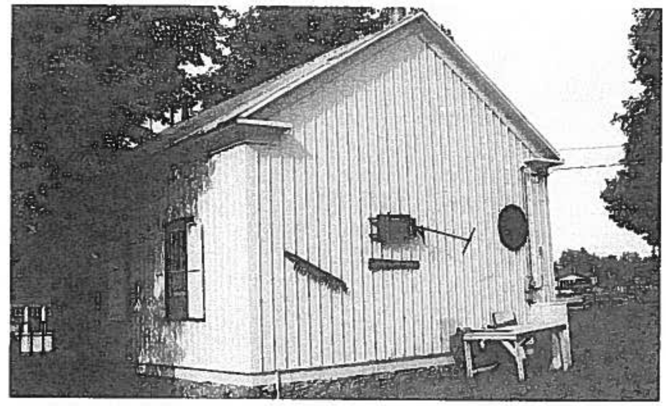
Two tables follow the description of control levels 0–6. Each column in these tables is a scale, listing in incremental order the improved activities and features that are distributed across the levels (physical situations 0–6). These scales can be used as a brief, structured inventory of features and actions in your facility by highlighting elements that match your situation. The result is a summary "readout" of pest-inhibiting features. The scales can also be used to indicate areas of possible improvement by moving to the next better feature in the column; for example, "Sheltered from rain and sun" to "Protected from weather, may have winter heating".

Level 0. A totem pole outdoors.

Level 1. A tarped agricultural machine.



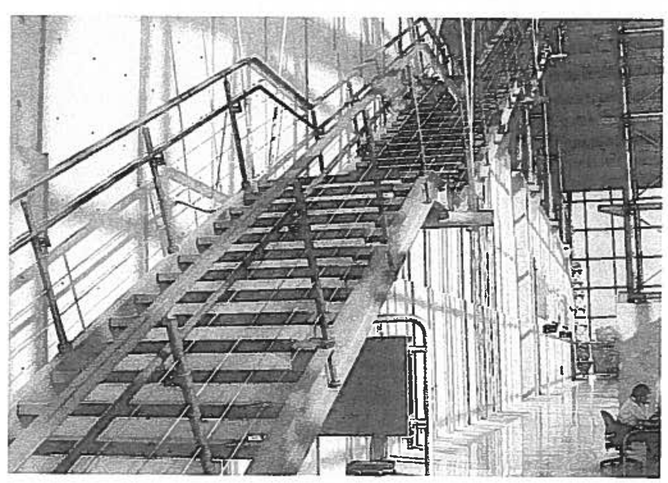
Level 2. A drive shed on gravel.



Level 3. A schoolhouse turned into a centennial museum.

Level 4. A former bakery turned into a technology museum.

Level 5. A century-old city block square museum.



Level 6. A national archive designed as a building within a building.

## Level 0 — Outdoors with unrestrained access by harmful agents

Starting from a situation of no preservation steps taken, this is the base level from which to evaluate the effectiveness of any improvements to block pests. Plan B presents the first steps to reduce the effects of pests in this situation.

| Common situation | Plan B |
|---|---|
| **Examples:** Building exterior, totem pole, public sculpture. | |
| **Site:** Outdoors, rural or urban, may be sheltered by trees, buildings, or landforms. May be well or poorly drained. May be windswept or sheltered. Urban sites are likely public spaces. Rural sites may be remote with little visitation. | Some environmental modification may be considered if the site is clearly harmful; for example, cutting back encroaching growth that physically disrupts structures, shelters pests, or induces higher moisture content by casting shade; cutting back clinging vines that disfigure, obscure, create a fire risk, etc. |
| **Building:** No exterior enclosure; fully exposed to year-round material weathering; object sitting directly on ground. | There is considerable preservation justification for moving objects under shelter. If that is not possible, in situ techniques should be considered. Use bird netting or enclosures made of sheet material (metal, tarpaulins) to block pests if the object is open to weather, collecting detritus, or housing animals (in the case of large machinery, derelict buildings). Install angled raincaps (e.g. on pole tops, exposed beam ends) where possible to reduce roosting and bird detritus that induces rot. |
| **Portable fittings:** None. | Separate rot-prone objects from the soil they are resting on: use compacted gravel; paved surfaces; a fungicide/insecticide-treated wood shoring; a short concrete plinth; or a moisture barrier (such as a sheet metal layer between post and pillar; where the sheet metal protrudes horizontally, bend it downward to avoid conducting splashed water into the joint). Use these solutions to reduce ground contact, slow fungal attack, and reduce burrowing insect access. Metal shields, which divide wood from foundation elements, will force termites to run their shelter tubes across the shield where they are readily detected, or carpenter ants to walk along visible surfaces, which improves detection. |
| **Procedure:** None. Abandoned to fate. | Routinely remove grime, soil pockets (which are a site for rapid biological activity), and all surface growths such as lichen, mould, moss, etc. Examine object for insect infestations, especially wood borers. Wood-borer activity can lead to structural collapse. Use residual pesticides or fungicides when warranted. Sealing wood to reduce moisture absorption is most effective when the sealing agent is applied on a smooth surface, or on minimally weathered new wood. Deteriorated surfaces allow easy paths to form that water can then follow into the interior. This condition supports systemic fungal attack. All surface treatments need to be periodically repeated as the surface of the object weathers. Be aware that borate fungicide and insecticide treatments can be washed away from wood surfaces. However, the solid borate rods and chips put into holes bored into timber do rely on wood moisture to migrate further into the wood and confer protection. Preservative fungicides and insecticides may stain surfaces; therefore, test first. Subterranean sections of an object near the surface of the soil can be excavated, approved fungicide applied, and surface drainage improved. The most rapid pest attacks generally occur in the soil just above the water table, where the soil is still oxygenated. Thank people for their contribution when they detect problems and report them to you. |
| **Prognosis:** Open to maximum algal, fungal, rodent, and insect attack. Chronic bird and bat roosting. Systemic effects due to pest attacks on the materials they are adapted to use. | Reduced algal, fungal, rodent, insect attack, and bird roosting. A range of surface to systemic effects is still expected because the object is exposed to the elements, but the damage has been reduced because of detection and remediation. |
| **Expected deterioration:** Noticeable effect or damage in one season, as rapidly as what can happen to a dead tree, mammal, insect, or leaf. Colonization of more resistant items by algae, moss, fungi, and plants in a few years. Anticipated effects show within a few years on robust items, and within a few days on delicate items. Self-sheltered parts of the object will retain features as noted in Level 1, but will eventually succumb to harmful agent attacks. | Noticeable effect or damage in one season. Anticipated effects show within a decade on robust items, and within a few days on delicate items. Self-sheltering parts of object will retain features as in Level 1, but will eventually succumb to harmful agent attacks. |

## Level 1 — Roof or tarp only

Basic shelter from rain and overhead sun is provided by an architectural element, an applied covering, or a self-sheltering part of the exposed object. In your action plan, include appropriate action elements from Level 0, Plan B.

| Common situation | Plan B |
|---|---|
| **Examples:** Poor enclosure in a wind-way or carport. Top of object sheltered by a shed roof or tarpaulin cover. | |
| **Site:** Outdoors, rural or urban, may be windswept or sheltered by trees, buildings, or landforms. Site may be well or poorly drained. | Some environmental modification may be considered if causing harmful effects (e.g. cutting back encroaching growth that shelters pests and induces higher moisture content by casting shade, or cutting back clinging vines that disfigure a structure or object). Eliminate obvious nearby pest attractors such as open garbage containers. Ensure roof is capable of withstanding a maximum snow and wind load. |
| **Building:** A roof or tarpaulin overhead with no complete wall. Structure protects against direct rainfall, prevents extensive fungal attack, and limits any mould-requiring boring insect attack. However, the structure will attract nesting birds, rodents, and insects seeking shelter. Does not stop rodent, bird, or insect access. | A roof must extend over the object to protect it from slanting rain. Note that damp air rises because it is lighter than dry air (water vapour is lighter than the oxygen and nitrogen gases that make up most of the air). Therefore, if tarpaulins are used to enclose an object, ensure that there is ventilation near the top ridge so that there is no prolonged entrapment of high humidity. A plastic tarp that does not ventilate at the ridge forms a dome over the object, and traps dampness underneath. You may have to reduce the moisture source from the ground or a slab on grade concrete floor by first laying a moisture barrier tarp underneath the object. Bird netting or spikes used where possible deter roosting, which in turn reduces detritus on a structure or sheltered objects. Coordinate the building of wire screen enclosures or cages with the provision of physical protection needs from vandals, climbers, etc. (i.e. improve security and pest-proofing simultaneously). Treat wood in contact with the soil with fungicides. |
| **Portable fittings:** None, contents of the enclosure rest directly on earth or gravel, or are semi-buried. | Where possible, separate objects from soil or gravel by using a short plinth, or insert a moisture barrier to reduce moisture from contact with the soil. Ensure the barrier drains properly so that puddles do not form against the object. |
| **Procedure:** No pest-control procedures other than the beneficial contributions of the original construction (e.g. mineral shingles, paint). Little site sanitation other than what is due to wind and weathering processes. | Consider improvements recommended in Level 0, Plan B. |
| **Prognosis:** Rodent or bird contamination in 1 year, structural insect attack in under 10 years, surface mildew within 10 years. Many harmful pests still have widespread access to sheltered objects. | Noticeable extension in the lifetime of smaller-dimension wooden elements by using remedial fungicide treatments, or breaking the wood's contact with soil, especially for wood species that deteriorate rapidly. Reduction of disfiguring animal nests and some wood-boring insects. Elimination of most structural fungal attack due to the low moisture content of sheltered objects. Surface mildew, moss, lichen, or algae are still present as a risk in humid environments. |
| **Expected deterioration:** Noticeable effect or damage in one season. Anticipated effects show within a decade to a century on robust items, within several years on soft materials, and within months on delicate materials. Self-sheltered parts of the object will retain features as noted in Level 2. | Noticeable extension in the lifetime of wooden elements due to remedial fungicide treatments. Noticeable effects show within several years on soft materials, and within months on delicate materials. Self-sheltered parts of object will retain features as noted in Level 2. |

## Level 2 — Roof, walls, and loose-fitting doors

This level offers more complete shelter from the elements. Contents may be exposed to wind-driven precipitation, oblique sun rays, excessive wind and wind-blown soil, snow, spores, and seeds. In your action plan, include appropriate elements from previous levels.

| Common situation | Plan B |
|---|---|
| **Examples:** Poor to fair enclosure: outbuilding; shed; poorly maintained house. | |
| **Site:** Commonly rural, sometimes urban. Drainage may have been improved by a small rise in elevation under or against foundations. Subterranean foundation is leaky. Structure may be sound if roof has been maintained, otherwise structural damage is expected. | Where possible, clear vegetation away from walls to reduce moisture damage and prevent encroaching plant roots from damaging the building foundation. Remove nearby dead timber to lower the incidence of wood-boring pests and deadfall hazards to structure. Improve drainage if water pools against the foundation or seeps into the building after a rainfall. |
| **Building:** Walls, wood, porous cladding, basic doors with gaps, rammed earthen floor, planks, plywood, gravel, asphalt, or separate concrete pad. Will not stop determined burrowing or gnawing pests because structural materials and wall construction are easily compromised. Protects against wind-driven precipitation, thus halting major fungal attack. Does not block insects because there are gaps in the structure. May limit large rodent and bird entry, but gaps allow small animals to shelter in the building. May attract roosting and nesting birds into eaves and insects into the building fabric. | Install bird netting on the eaves or wire caging over openings where possible to reduce animal entry and subsequent detritus collecting around and in the structure. Coordinate construction of enclosure with physical protection needs (e.g. improve security and pest proofing simultaneously). Improve or fix exterior sheathing if it has been compromised. |
| **Portable fittings:** Contents resting on hard floor can become damp from permeating ground moisture on which fungi could grow. | Rudimentary shelving limits moisture transfer from the damp ground or building foundation pad to the object. Putting objects up onto shelves will lower chance encounters with some pests. If appropriate shelving is not available, at least use heat-treated pallets, or lumber wrapped in plastic sheeting, to separate objects from contact with the moisture in an earthen floor. To avoid damage from minor floods and persistent moisture, elevate large, heavy items off the ground, and rest them securely on cast concrete pads or on treated timber blocks that have a moisture barrier underneath that prevents moisture being conducted into objects. Prevent heavy objects from sinking into the soil, as this would allow direct access by microorganisms and other wood-destroying pests. |
| **Procedure:** Animal nests removed. Groundskeeping around building consists of annual to monthly cutting back grass and foliage. | Routinely sweep interior spaces to eliminate wind-blown detritus and spider nests. Immediately remove wasp nests and bird nests. Use fabric (moisture permeable) tarpaulins as drapes over complex, hard-to-clean objects to reduce dust accumulation, prevent flies from spotting surfaces, allow moisture to dry after humid periods, and help reduce surface mould growth. |
| **Prognosis:** Expect fly specks, rodent invasion, insects grazing or crawling over stored materials, especially in cluttered, unchanging, unexamined areas. Water-staining and possible fungal attack after heavy rain accompanied by winds. Pests have free range, so all contents can be affected. | Reduction of disfiguring animal nests by removing them and early remediation of pest attack through targeted pesticide use or physical methods. |
| **Expected deterioration:** Anticipated effects show within a century on robust objects, within a decade on soft materials, and within a year on delicate materials. | Reduced frequency of many insect attacks compared to lesser sheltered situations. Minimal structural microbial activity, and greatly reduced surface activity. |

## Level 3 — Basic habitation

Human housing that has reasonable protection from the effects of climate and coarse control of the interior environment through basic heating or ventilation. In your action plan, include appropriate elements from previous levels.

| Common situation | Plan B |
|---|---|
| **Examples:** Fair enclosure: western-style housing up to the early 1900s; public buildings such as churches, palaces, etc. Average maintained historic civic buildings, temples, shrines. | |
| **Site:** Garden landscapes, walkways, lanes, streets. Drainage into open ditches, roadways, rudimentary sewer. | Limit the growth of trees and shrubs against the structure to protect vulnerable foundations against damage from encroaching plant roots. |
| **Building:** Reasonable attempt to fully enclose the building to protect it from bad weather to make a liveable building with some comfort during the annual climate cycle. Gaps generally small if building has basic heating, but exterior cladding may allow determined or occasional rodent access. Has single doors for entry, loose-fitting sash windows, possibly no screens. Internal partition walls have crevices along the floor that can house insect life. Open fireplaces, flues, hollow space under floors, and roughly finished attics allow bird, rodent, and insect access into structural voids. Some natural ventilation is possible to alter interior temperature or humidity, but there is no air conditioning system. | Use screen doors and screens on windows to reduce insect entry and allow ventilation. Reduce structural gaps and spaces around habitually used openings (doors, windows) to under 5 mm to limit rodent entry. Ensure eavestrough has outflow pipes to carry water well away from foundations, which will reduce potential for mould growth. Screen unused flues at the roof level to block bird and insect access. Use heavy gauge, plastic sheet "soil covers" over enclosed earthen-floor crawl spaces. Ensure good, screened ventilation of this space to further reduce its humidity, otherwise wooden structural elements will be susceptible to fungal and insect attack. |
| **Portable fittings:** Some objects are displayed inside the building as they were originally used (historic interior), and others are stored in closed rooms on shelves, in slightly or fully open boxes. Some objects may be stored in cabinets for security, but the enclosure's resistance to pests is generally poor. | Place objects vulnerable to insects in well-sealed display or storage cabinets (ensure that any gaps are less than 0.3 mm). Consider operating portable dehumidifiers to restrict relative humidity to under 75% over a short, damp period (i.e. 2 months), and under 65% in year-round, high-humidity climates. Consider using polyethylene bag enclosures (installed during dry season), or fabric covers for soft items in storage to reduce pest incidence. Delicate items should be placed in lidded boxes or cabinets. |
| **Procedure:** Spring and fall cleaning, household vacuuming, and dusting exhibits may also occur when build-up of dirt is noticed. | Do not place objects in underground areas if you cannot ensure good ventilation or flood control. Inspect attic and basement areas annually for severe pest problems. These spaces often fulfil a pest's needs more than the inhabited floors do. |
| **Prognosis:** Multiple rooms can be affected, chronic outbreaks of paper and fabric pests could be supported. Storage in damp basements or hot attics are retrograde choices for object survival. | Reduced chronic fly and dermestid problems because of increased control over attic space. Reduced silverfish and mouse problems because of increased control over conditions in basement and crawl spaces. |
| **Expected deterioration:** Anticipated effects appear within an equivalent time to the building's lifetime on robust objects, within decades to a century on soft materials, and within years on delicate materials. | Reduced rodent, insect, and fungal damage because of increased sealing of the building and routine sanitation activity. |

## Level 4 — Adapted commercial

Adapted civic structures built for large-scale inhabitation, industrial processes, or business activities. Historic structures that possess elaborate architecture. In your action plan, include appropriate elements from previous levels.

| Common situation | Plan B |
|---|---|
| **Examples:** Good enclosure: basic professional, commercial, or civic building adapted to museum, archive, or gallery use. | |
| **Site:** Drainage ensured close to foundation walls, but overall site may not yet be adapted to 100-year cycle of weather extremes, or is affected by adverse elements from neighbouring properties, which are strong pest attractors. | Include in the site development planning the means to reduce the possibility of flooding and to eliminate places where rodents could live. |
| **Building:** Often has a mineral-based exterior surface (e.g. jointed stone, brick). Has multiple doors to the exterior, a mudroom, or a divided entrance hall. Single layer of doors, such as emergency exits, are sealed tightly with brush strips, rubber blades, and rodent-proof metal. Structure has an HVAC system for air conditioning, heating, and forced air movement. | Improve sealing of doors, windows, and other perforations to prevent pest access. Improve interior partitions to limit rodent travel by reducing gaps under doors and screening perforations. |
| **Portable fittings:** It has exterior garbage bins or a purpose-designed loading bay garbage collection area (the bay is inside one exterior door, but has a well-fitting inner door that cuts the bay off from the corridor). More extensive use of display cabinets, which may not all be insect proof but greatly lower the incidence of insect infiltration. All collections are placed on shelving or on pallets. There may not be easy access for pest inspections throughout the storeroom because of overcrowding. Hallways are also used as overflow storage. | Create an enclosed space for quarantining incoming goods and artifacts as well as for disinfesting new acquisitions. Obtain a chest freezer, $CO_2$ fumigation bubble, or nitrogen treatment chamber. Train several staff to properly and safely use this equipment and to comply with regulations. Incorporate inspection needs when rehousing collection. |
| **Procedures:** Basic visual inspection of collection arising from its use rather than from systematic inspection. Few traps used in areas with major exterior openings. Annual storage room sanitation procedures limited to vacuuming, but only in corridor spaces, not under lower shelves. Gallery cleaning more frequent, but does not keep up with dust, litter, hair, etc. that is deposited in restricted spaces. | Conduct annual cleaning, reduce clutter, vacuum under shelving, inspect rarely accessed collections. Quarantine and eradicate pests before objects are introduced into collections. With an established IPM program and a low internal pest incidence, new collections are the highest risk for introducing infestation, along with used packaging and food service activities. Disposing of garbage (especially foods) on a daily basis and immediately cleaning spills is necessary. Hire a pest control operator (PCO) to clean public food areas. Hire a PCO to clean collection areas only if heavily infested and in need of remedial action (baseboard sprays only, avoid area fumigation or pesticide application on objects). Use a trapping program to detect pests. If the building is reasonably tightly enclosed, regular trapping will tell more about what is going on in collections than what is crawling into the building that day. |
| **Prognosis:** Expect local outbreaks of pests, caused from importing pests along with objects rather than from building infiltrations. Insects are more commonly imported than rodents. | Reduction of chronic textile, fur, and skin/hide pest infestations. Annual levels may be chronic, but should occur less often and with less severity. |
| **Expected deterioration:** Anticipated effects show up within the equivalent time to the building's lifetime on robust materials, within a century on soft materials, and within decades on delicate materials. | Less frequent infestation by insects than seen in previous levels. |

## Level 5 — Purpose built

Building designed as a museum, gallery, or archive accompanied by increased planning that integrates policies and features to include pest control with control of other agents of deterioration. Include appropriate elements from previous levels.

| Common situation | Plan B |
|---|---|
| **Examples:** Purposefully designed as a museum, archive, or gallery. Improved enclosure meets preservation requirements. Enhanced commercial construction that provides spaces and features designed to store and display collections. | |
| **Site:** Site planning includes perimeter control of neighbouring risks by environmental modification (e.g. creating buffer zones, limiting pooling of water, and pruning dense foliage to lower fire hazard). | |
| **Building:** Designed with consideration for pest control such as providing a room to support freezers, controlled atmosphere fumigation, and quarantine needs. Smooth flooring, coved junctions with walls for easy cleaning. Light-coloured finishes and good lighting to aid pest detection. Pest-resistant exterior wall materials and fewer crevices when built in order to lower HVAC losses and reduce wall moisture issues. | Crevices discovered to be housing insects are caulked with appropriate sealant. Exterior window seals are maintained promptly to exclude wall moisture, and improvements are made to seal all exterior doors when flawed installation is discovered or materials fail. Improved HVAC filtration to "MERV 9" level to eliminate mould spore and pollen transport. |
| **Portable fittings:** Intensive use of protective cabinets increases the need for planned visual inspection. Many objects not on display, so there is a delay in finding outbreaks without a planned inspection. Little consideration given to cleaning underneath displays over the long term of a permanent gallery's life. High traffic leads to accumulation of litter – some of which can support pest life. Enclosed exhibits constructed to a level of tightness that excludes insects (gaps of 0.1–0.3 mm). Have capacity to treat routine volume of artifacts in walk-in freezers (-25 to -30°C) or controlled atmosphere fumigation. | Exhibit techniques that use showcase furniture or permanent diorama constructions are examples of objects that can provide hiding places for pests near areas of high visitor traffic. Consider reducing these long-term hazards for eventual pest colonization by designing for ease of access into the display and into hidden spaces underneath. Periodically clean these enclosures to remove detritus (fibre, dust, food particles, etc.). Promptly remove food garbage, which should be in closed containers and emptied daily, to reduce support for mice. |
| **Procedures:** Systematic, detailed inspection for pests. Comprehensive use of adhesive traps for pest detection. Bird proofing of structure. Commercial pest control operator (PCO) to disinfest the on-site restaurant. Permanent cleaning staff and security are not trained in IPM practices. All new acquisitions are subject to quarantine, inspection, and pest eradication processes. International loans of objects must be packaged in materials that support current import/export restrictions designed to limit the spread of wood pests. Only certified wood (heat treated) or exempted wood products used in packaging. | In larger institutions, consider using a zoned IPM system to indicate the most vulnerable areas needing special precautions and protection against pests. Visually inspect the most sensitive and valuable objects annually. Give all permanent staff basic IPM training to sensitize them to pest problems and methods of prevention. Elevated degree of storeroom sanitation is recognized as an effective pest-reduction activity. Clean non-traffic areas, including under-shelf spaces in storage rooms, annually. |
| **Prognosis:** Sporadic outbreaks associated with non-collection areas and events. Older storage cabinets may continue to show higher incidence of infestation because they are more porous, and because pests live in high-density arrangements of cabinets. | Sporadic pest problems occur with new collections and returning loans. |
| **Expected deterioration:** Anticipated events show up in a similar time on robust and on soft objects, and within a century on delicate objects. | Less frequent sporadic pest outbreaks due to early intervention and effective remediation. |

## Level 6 — Preservation designed

A collections facility whose primary function is long-term preservation. Provides an excellent enclosure, with multiple layers that block routine hazards, and is designed to reduce calamities. In your action plan, include appropriate elements from previous levels.

| Common situation | Plan B |
|---|---|
| **Examples:** Purpose-designed preservation enclosure; full spectrum of pest-reducing features incorporated such as a refrigerated herbarium collection building, an ethnographic fur storage room, and extensive use of tightly sealed cabinetry for all collections. | |
| **Site:** Construction conforms with the need to fully manage for an expected 100-year cycle of weather extremes. Exterior plantings controlled, and sanitary perimeter managed as noted in Level 0, Plan B. Use of food processing plant techniques such as gravel borders on geotextile (engineered fabric underlays that control soil movement) to lower rodent pressure (see Imholte 1984). Exterior wall sheltered under protective eaves as noted in Level 1, Plan B. | |
| **Building:** Design clearly based on collection preservation needs. Construction phase requires establishing trust between conservation and construction professionals to discuss these needs when details are decided and executed. A perimeter corridor buffers storerooms from effects of the outside environment better than a single wall. Poured concrete, slab or wall junctions sealed and maintained. Storage areas separated from high human occupancy activities. Floor sweep on interior doors restricts insect movement. Installing pipe and wiring chases minimizes wall perforations. Holes are sealed with appropriate materials that maintain room-to-room quarantine. Built-in vacuum, or portable HEPA vacuum units, are used to control dust. Cabinets throughout the building are tightly sealed. HVAC system has to be designed to eliminate particulate contaminants and spores if there is significant storage on open shelving. Pest-control facility near loading bay provides quarantine and treatment area including enough room to store travelling exhibit packaging. Cooled food waste and garbage storeroom. | Equip HVAC system up to MERV 13, which eliminates particulate contaminants including dust mite faeces. Plan cool room storage to inhibit insect motion and lower chemical deterioration rate (e.g. rooms kept at 15°C). However, this solution requires careful design, commitment to maintenance, and energy use. Construction project includes strict control of details, such as vapour barriers, due to the high performance expectations for the building's envelope. Structure and contents disinfested before occupation, which requires coordination of pest-control operations when the collection is moved in. |
| **Portable fittings:** Light traps positioned to draw insects out from loading bay. Bird curtains or shrouds connected to truck trailers block most pest access when doors are open. Appropriate system (-20 to -30°C freezer, controlled-atmosphere fumigation, heat chamber) for eradicating infestation of new acquisitions. | Cabinet integrity protected by an annual inspection and maintenance plan. Near hermetic storage (e.g. film canisters) can be used for most valuable and vulnerable items in long-term storage. All disinfested objects sealed in pest-resistant enclosures, possibly refrigerated, possibly in an altered storage atmosphere. Walk-in storage freezers with back-up power supply used for routine pest control. |
| **Procedures:** Structural flaws promptly corrected, crevices caulked. Routine trapping near openings of each room and vulnerable collections databased and mapped for long-term analysis. Annual visual inspection of susceptible collections. Storage areas kept at temperature set primarily for human comfort (which does little to suppress pest growth). Contents are sterilized, sanitized, fumigated, cleaned, and inspected (depending on requirement for long-term storage) before being hermetically sealed or deposited in tight, pest-resistant containers. Bagged, in vials, or boxed artifacts all placed in pest-resistant cabinets. Visual inspections conducted to confirm integrity of seals and absence of pests on an annual basis. For refrigerated storage, all contents are sealed against refrigeration failure and moisture movement. A recovery plan is in place in case of mechanical failure. New staff are trained in IPM policies and methods. Maintain work relationships through an IPM committee and informal connections with the staff who encounter pests (security, maintenance, food services). | |
| **Prognosis:** Few pest issues in storage areas. More found by floor trapping than by inspecting cabinets visually. A few pests found in gallery spaces due to human traffic and food service. | Sporadic pest problems, mostly in new collections and on objects returning from loan. |
| **Expected deterioration:** Anticipated pest events are minimal over the presumed lifetime of the storage structure for robust to delicate objects. Long-term survival of objects is tied to cultural will to preserve the contents, structural integrity of the building, and energy to support necessary services. | |

## Progressive scales of IPM components

Column headings reflect activities and structural concerns that affect IPM in collection facilities. Use these headings to highlight elements your facility has. Notice the implied scale of improvement that is built into the previous Level 0 – 6 tables.

| Level and situation | Examples | Avoid | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Environment | Site | Object condition | Food waste | Lighting | Plants | Sanitation |
| [0] Outside | Totem pole, farm machine | Local climate and weather | No modification | Infested | Strewn throughout and around | Ambient natural or city lighting | Nearby flowering plants and deadwood sources of insect pests | No cleaning except by natural weathering and wind |
| [1] Roof, tarp | Shrines, under eaves | Sheltered from rain and sun | Possibly elevated, roof drainage | | Consolidated in open containers | | Encroaching foliage cut back (reduce moisture damage) | Dry sweeping raises dusts, but may damage some insects |
| [2] Roof, walls, and loose-fitting doors | Temples, sheds, barns | Sheltered from some wind-blown dirt and snow | Simple foundation drainage | Cleaned | Consolidated in closed containers | Some interior lighting | Cut back encroaching trees (reduce root damage) | Clutter provides pests with shelter and interferes with inspection |
| [3] Basic habitation | Historic homes, churches, temples | Protected from weather, may have winter heating | Subterranean foundation drainage | Sanitary | Hauled away weekly from exterior containers | Some lights mounted on exterior | Avoid cut wildflowers or inspect for insects before bringing indoors | Household vacuum and damp mop to capture dust and insects |
| [4] Adapted commercial | Civic archives, private gallery | Climate controlled by HVAC to eliminate extremes | | Disinfested | Removed daily from interior, hauled away weekly from exterior, closed containers | Mandated security lighting over doors | Restrictive policy includes inspection, treatment, or ban of high-risk vegetation (primarily local, cut wildflowers) | Clutter localized in designated workrooms |
| [5] Purpose built | Provincial and national museums up to the early 1900s | Climate controlled by HVAC to year-round human occupancy requirements | Site-wide floodwater drainage | | Exterior compactor (rodent proofed) | Low-pest-attraction lights (UV poor) on exterior | Nearby exterior: only non-flowering plants. Interior: only greenhouse cut flowers or healthy house plants in sterilized soil | Built-in vacuum system (bag room) isolates dust and captured insects |
| [6] Preservation designed | Collection preservation centres | Climate controlled by HVAC to meet object preservation needs; low-temperature storage to control pests | Designed to manage 100-year cycle of extremes | | Well-sealed interior garbage room (cooled) to control rodent and insect access | Attractive light draws insects from exterior walls and openings, light traps near entrance ways | | HEPA vacuum portable units or built-in vacuum system with filters |
| [7] Ultimate | | Optimal for all objects | | Sterile | No food waste production | | No plants that are attractive to pests | Clean room air supply |

## Progressive scales of IPM components (*cont.*)

Column headings reflect activities and structural concerns that affect IPM in collection facilities. Use these headings to highlight elements your facility has. Notice the implied scale of improvement that is built into the previous Level 0 – 6 tables.

| Level | Block | | | | Detect | Respond | | Recover |
|---|---|---|---|---|---|---|---|---|
| | **Physical barrier** | **Physical resistance** | **Object enclosure** | **Object shelving** | | **Maintenance** | **Suppression response** | |
| [0] | No barriers to pests | Intrinsic to object material | Intrinsic to object construction | Objects on ground | No inspection | No maintenance | Predators, disease, weather | No recovery, no accounting of cost |
| [1] | Structure may encourage bird roosting | Sheathing easily chewed or infiltrated | | May sit on plinths, pallets | Annual visitation | Replace roofing, replace tarp | Residual pesticide, fumigant application to entire collection | |
| [2] | Perforations may allow rats, birds access | Sheathing gnawed by rodents and insects | Cardboard boxes | Gravel, concrete slab | Unplanned observation during use | Repair structural failures as found | Pesticide application targeted to specific outbreaks | |
| [3] | Perforations may allow mice access, window and door screens block insect entry | | Chests, fabric bags, jars, dressers, cupboards, gaping cabinets | Pantry shelves, sit on wood floor, carpet | Daily familiarity, inspections associated with incidence | Repair exterior seal failures as found | Low temperature, easy to obtain (control moisture risk, monitor for refrigerant leak hazard) | Thorough cleaning after infestation is treated to ease finding new outbreaks in future inspection program |
| [4] | Perforations may allow large insects access | Some mineral-based sheathing (jointed stone, brick) less prone to rodent or insect attack | Sealed wood cabinets, adapted commercial display cases, insect-resistant bags (polyethylene) | Sealed wood or metal racks elevate objects off floor | Periodic inspection of exterior and interior, incoming objects quarantined and visually inspected | Repair interior seal failures and interior building fabric to support preservation needs including pest exclusion | Controlled atmosphere fumigation, increases treatment capacity (assume high-pressure gas supply hazard) | Managerial analysis of pest control problems, accounting of basic capital and contract costs |
| [5] | Perforations may allow small insects access | Mineral-based or metal sheathing impedes rodents and insects | Some tight metal cabinets, rest are wood with loose seals | Metal racks elevate objects off sealed concrete floor | Systematic use of rodent and insect traps to map problem areas, vulnerable objects inspected | Improve exterior building fabric to support preservation needs | Elevated temperature treatment, increases throughput (controlled incremental thermal aging above natural rate) | Make physical improvements through capital planning (passive features) |
| [6] | Perimeter control blocks insects (perimeter corridor increases detection) | Near seamless sheathing resists rodent or insect attack | All metal cabinets, gaskets, compact shelving allows total floor cleaning | Compact shelving | Sensitive collections visually inspected annually | Replace aging components before failure | | Make procedural improvements (active features), accounting of all internal labour costs |
| [7] | Hermetic | Metal can | Cabinet contents in cans, vials, or boxes with hermetic seals | High-density, robotic retrieval warehousing | All objects visually inspected annually | | | |

## Thermal control application guides

Unlike fumigation and pesticide use, thermal pest control is available to nearly everyone if they know how to achieve it. The following is a simple guide to estimate temperature and time required for effective thermal control, and to create the environment needed to kill insect pests.

### *Estimating time and temperature for thermal control methods*

The most common question asked about applying thermal control is how long? This is discussed in sufficient detail below to help make good decisions.

Figure 15 (p. 34) shows the time needed to kill insects by thermal methods. The two lines on the plot show the range of times and temperatures commonly used for treatment. Please note the logarithm scale of time is marked in days, but other familiar units lie above, centred on the individual words. For those unfamiliar with logarithms, the first interval marked by a tick following the $10^1$ (10 days) mark is 20 days, the second interval is 30 days, and so on. The value of $10^{-1}$ means 1/10th of a day. The term "moribund" describes the condition of the insects, but when that happens is variable by species, as shown by the wide distribution of mortality data, especially at lowered temperatures.

"Dead" status is defined by a line drawn just beyond the edge of the mortality data. This is likely a conservative estimate because the experiments were based on fixed increment inspections for any survival or recovery, rather than on looking at the subjects in real time and noting when they appeared to expire.

As can be seen, the low-temperature exposure method requires more time to be effective than the high-temperature protocol. Also, most low-temperature mortality occurs before and at warmer temperatures than the indicated limit line. This spread in the low-temperature data leads to various interpretations of the correct protocol. Some protocols have been specified to facilitate rapid treatment based on knowledge of the species after reviewing the data set. For such decisions, and a more detailed discussion of the data, please refer to the source paper (Strang 1992).

The boundary to the data supports a "worst case" recommendation, i.e. the material is suspected to be infested by insects, but the pest is unknown, and full control is desired. A -30°C exposure for a week or -20°C for 2 weeks will suffice. This method also presumes the objects come out of a month in warm storage, not from a cold outdoor environment in which some pest species could adapt to cold and subsequently survive such low-temperature exposure. In practice, the -30°C and -20°C exposures have usually been successful at shorter times (a few days at -30°C and a week at -20°C) because the species comprising the sparser data along the boundary are less common pests in collections (see Strang 1992 for details).

For high-temperature control, 55°C is a good maximum exposure limit. However, because the mortality of insects at this temperature is nearly instantaneous, the limiting factor is the rate of heat penetration through objects, which is illustrated in Figure 16 (p. 35).

Figure 16 can be used to determine the time needed to change the temperature of an object (points), and to predict the bulk change in moisture content if it is subjected to drying or humidification (lines). As in Figure 15, please note the use of logarithm scales. The range of values would be difficult to present otherwise. Common descriptive terms are provided to help interpret the scales.

If you imagine an object fitting inside a rectangular volume, the smallest dimension is the one referred to as thickness in Figure 16. For example, the "thickness" of a piece of wood measuring 2 in. x 4 in. x 8 in. would be 2 in. (50 mm). Finding this dimension in millimetres on the scale allows one to determine the approximate time for "half response". The half response time is how long it takes for the object to go from the start condition to half way to the end condition (for example, when going from 20 to -20/-30°C, the time to get to -5°C is the half response time). It will take roughly the same time again to go to the 3/4 point, and the same time again to go to the 7/8 point, and so on. This response time is influenced by the material's insulation properties. A key is given to show the source materials tested. You can interpret a time based on evidence from this key, or simply take the most conservative value (largest number, top of the point distribution at the specified thickness). The half response is used because it is much easier to measure than the completion point. To figure out the rough time to completion, multiply this response time by four or five. If you want to keep the treatment as short as possible, do not rely on the estimate, instead use a test block of similar material in which a thermometer probe is inserted in order to measure in real time when to terminate the treatment.

For heat treating, the line in Figure 16 marked "wood bagged in 6 mil PE at 60°C" shows that enclosing objects in a vapour barrier before heating confers added protection against desiccation. This is a simple and common method. While the plotted lines demonstrate that paint and even "stagnant" air (technically called the "boundary layer" of air) will act as barriers to moisture loss, a simple plastic bag is the most effective and highly recommended. While there is a condensation risk inside a plastic bag during cooling after a heat treatment, letting the temperature of the container drop slowly so the dew point is not experienced inside the bag can greatly reduce this moisture hazard for sensitive objects. Wrapping the object with absorbent dunnage (e.g. a cotton sheet) before bagging also provides a rapidly acting buffer to stabilize moisture content during treatment. For a full discussion of these factors and hazard mitigation, see Strang (1995, 2001).

During low-temperature treatments, exposure to condensation on removal or to dampness from complete failure of the freezer is prevented by using vapour-resistant bagging, and leaving it on through the re-warming phase. Leaving objects in bags can also prevent reinfestation if the storage area has not yet been decontaminated. Long-term storage in vapour-resistant bags can be beneficial as long as four conditions are not allowed to occur that would promote mould growth inside the bag. These recommendations come from observing the moisture sorption isotherms for organic materials and behaviour of moisture in bagged objects. To understand the relative risk being discussed, at 65% RH, mould growth is just possible to maintain in laboratory experiments, but at this level is very unlikely to initiate spore germination. Therefore, 65% RH represents a lower limit to mould formation. Deriving from microbial research, RH is a more appropriate measure of the water available for organisms (an equivalent to water activity) than the equilibrium moisture content (EMC) of the material on which the mould may grow.

1) Do not bag objects that have equilibrated above 65% RH for long-term storage. You will simply be trapping in moisture at a level that, in time, can support mould growth.
2) Do not bag objects that have equilibrated near 65% RH and subsequently store them in warmer conditions. The rise in temperature allows moisture to leave the object and elevate the RH in the bag toward levels that support microbial life. This only holds true until the upper limit in temperature for the mould is reached. Heat treatments to control pests are too high in temperature and too short in duration to support mould growth.
3) Do not bag objects and store them resting on a hot or cold surface that induces a thermal gradient (e.g. in winter, a cold concrete floor in a heated garage). This gradient causes moisture to accumulate in the colder side of the bag. This is a "mode of failure" in shiphold transit environments and in other similar situations. The resulting dampness leads to the bagged items spoiling.
4) Do not bag objects near 65% RH and then store them for a prolonged time in air that has a significantly higher RH. The moist air will eventually permeate the bag. The timeline for this may be many years: the governing factors are quality of the barrier; whether there are pinholes in the bags; and the volume of the object providing buffering capacity in the enclosure. In the meantime, beneficial effects will be significant. If year-round humidities are expected to be above 65% RH, a mild controlled drying of objects for long-term packaged storage can be a method of preserving highly vulnerable items in these difficult environments. Including RH measuring strips in the bags to provide an early warning of problems and periodically checking them would be advisable.

All of these situations are unlikely to cause mould problems in short-term pest treatments because of a lack of time for mould response, or because of temperature limits that prevent growth (too hot or cold).

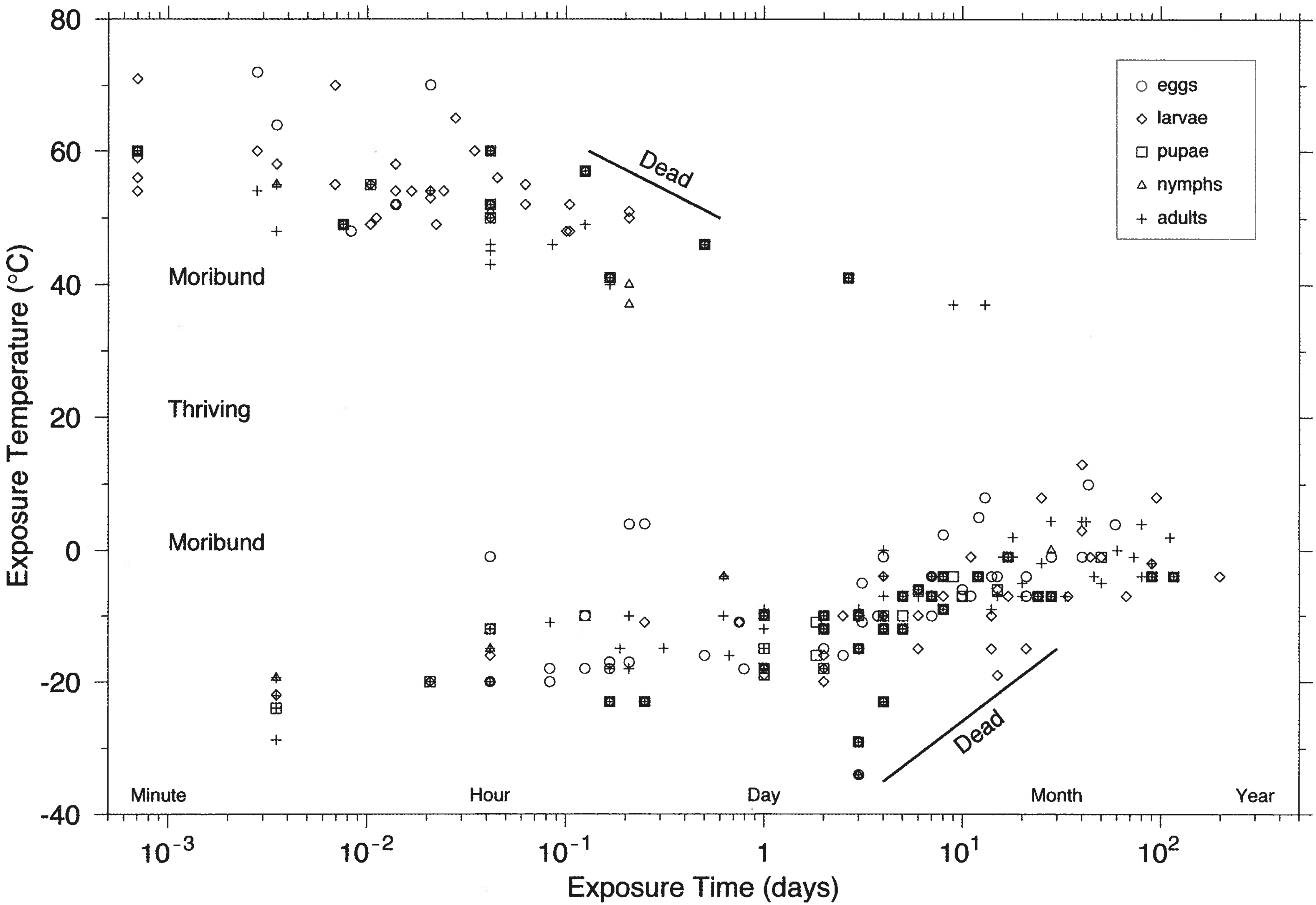



*Figure 15. Thermal mortality of insects, all stages, for 46 museum pest species (Strang 1992, 2001).*

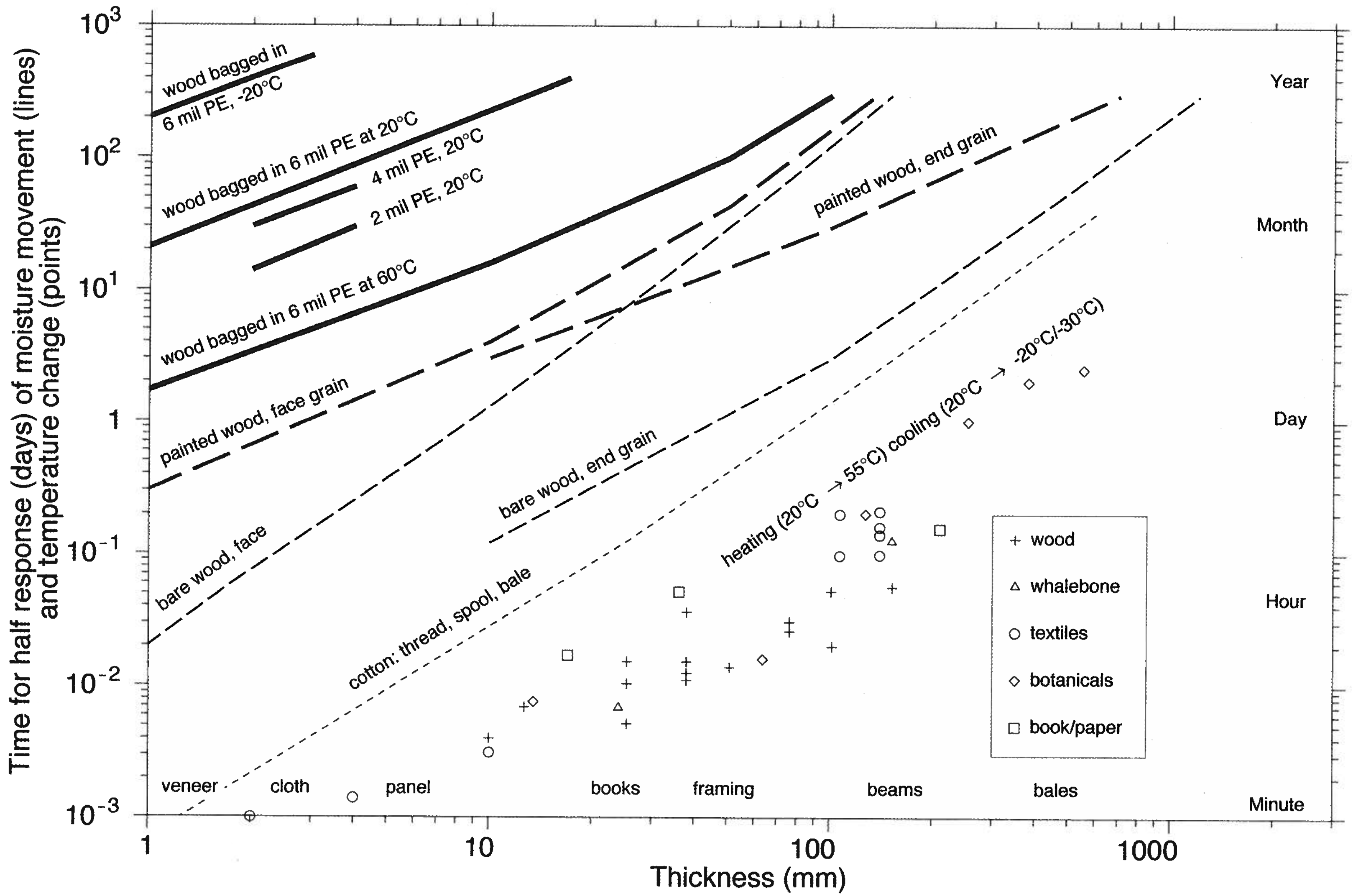



*Figure 16. Equilibrium of organic materials to moisture and thermal change (Strang 1995, 2001). PE = polyethylene vapour barrier film.*

## Low-temperature control in a chest freezer or outdoors

This method is quite simple, but a few guidelines noted in the captions on the drawing need to be observed to ensure that it will work. Similar guidelines to ensure pests are killed and damage to objects is avoided should be followed when exposing objects to the cold outdoors. Outdoor exposure also requires maximizing cooling while preventing solar heat gain (e.g. use a light-coloured tarpaulin).

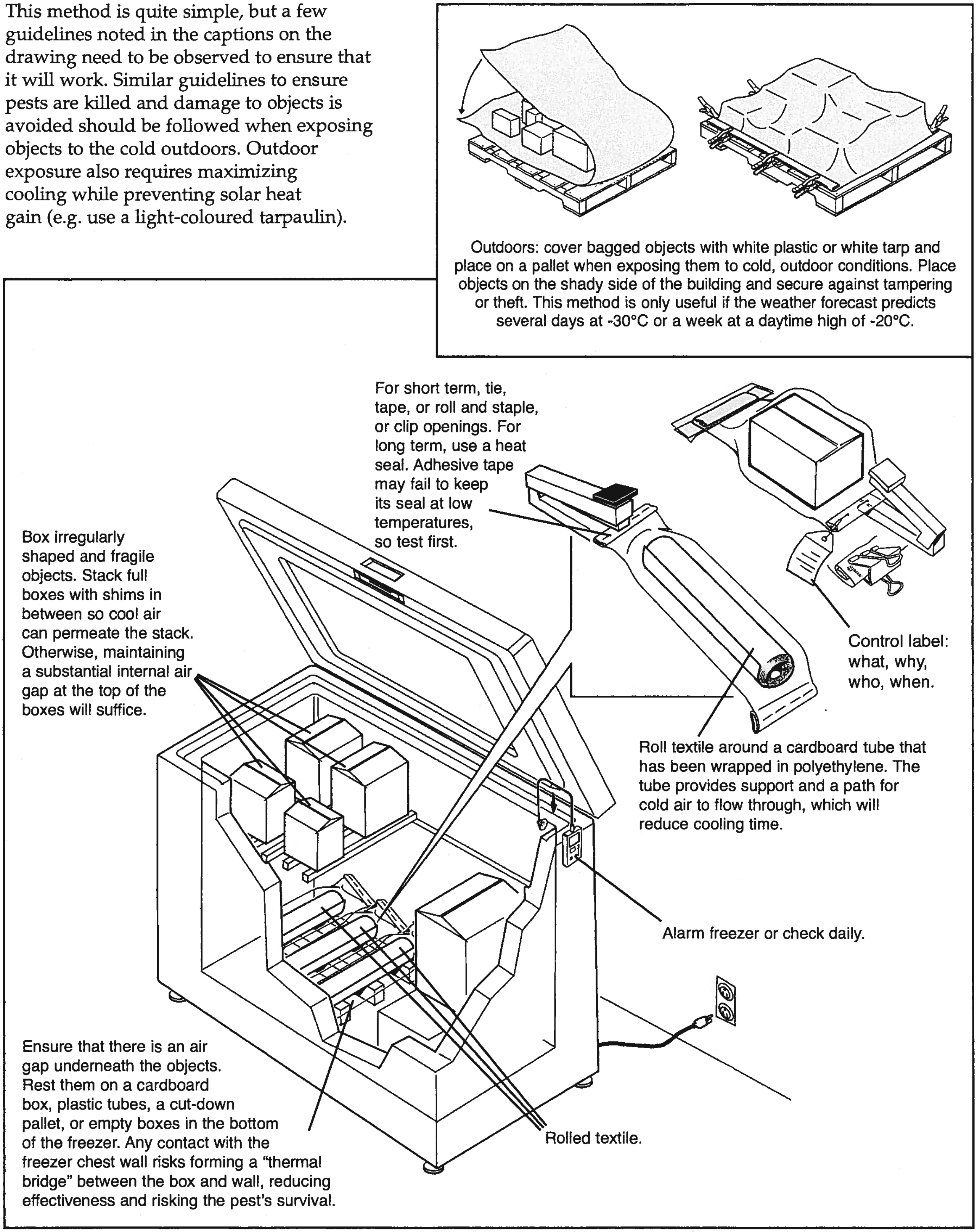



*Figure 17. Low-temperature control in a chest freezer.*

## Heat disinfestation box

A wood shipping crate can be modified to make a heat disinfestation box, as shown in the diagram below. Heat is provided by one or two 1500-watt industrial, metal-bodied heat guns or an equivalent industrial hot air source. Do not use plastic hair dryers or household heaters because they are not designed for continuous operation at the necessary temperature. Safety is a primary issue. A Canadian Standards Association (CSA) approved heat source is placed outside the box, blowing heated air, mixed with room air, into the metal duct, which is insulated from the crate by an air gap. This technique must be supervised at all times. Pay attention to the thermometer readings especially if the box does not have automated temperature control.

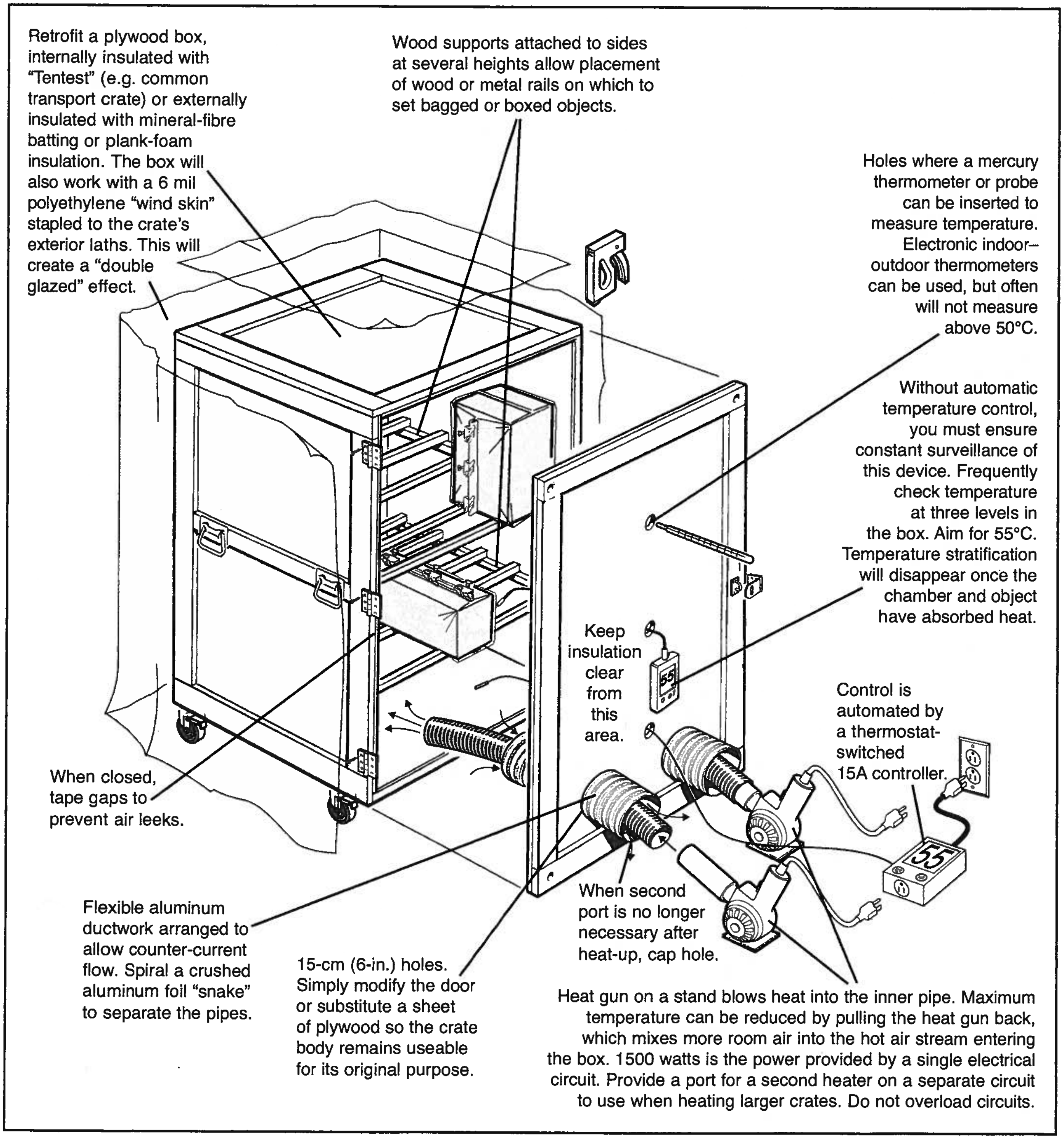



*Figure 18. Heat disinfestation box.*

## Solar disinfestation plenum frame

This simple frame provides sufficient heat gain from spring to fall when used on a clear day in Canada to disinfest thick, folded textiles or other materials. The plenum design transfers heat to the shady side of the object bag, eliminating the risk of dampness forming on the shade side of the object. It also speeds up the disinfestation process. Use a thermometer to measure the temperature on the surface of the black bag containing the object, or a temperature probe or wireless thermometer inside the object bag. When the temperature appears to be rising too high (above 60°C), you can control it by turning the frame off-axis from the sun. The frame should be tied to a support to prevent the wind from toppling it.

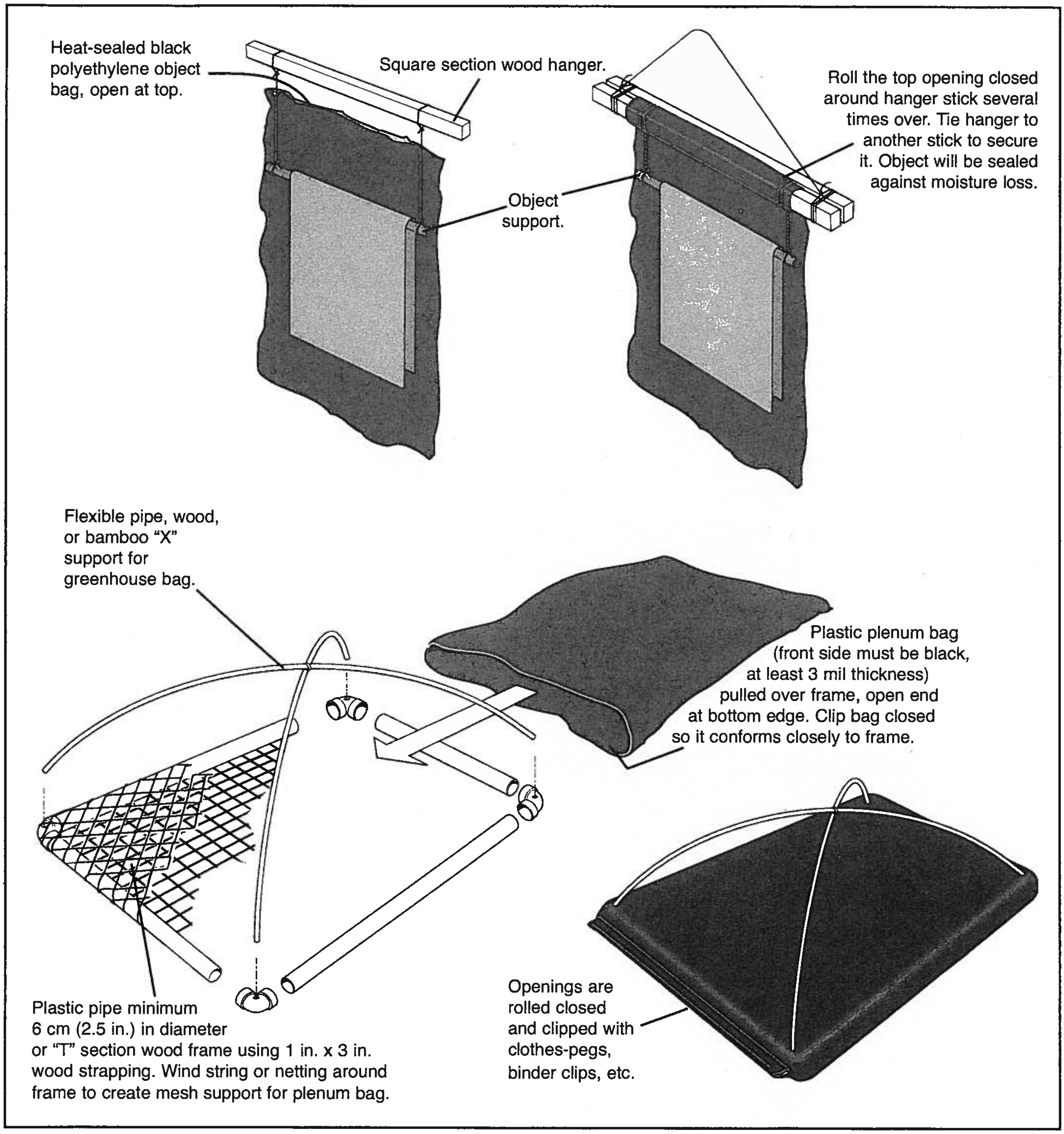



*Figure 19. Solar disinfestation plenum frame.*

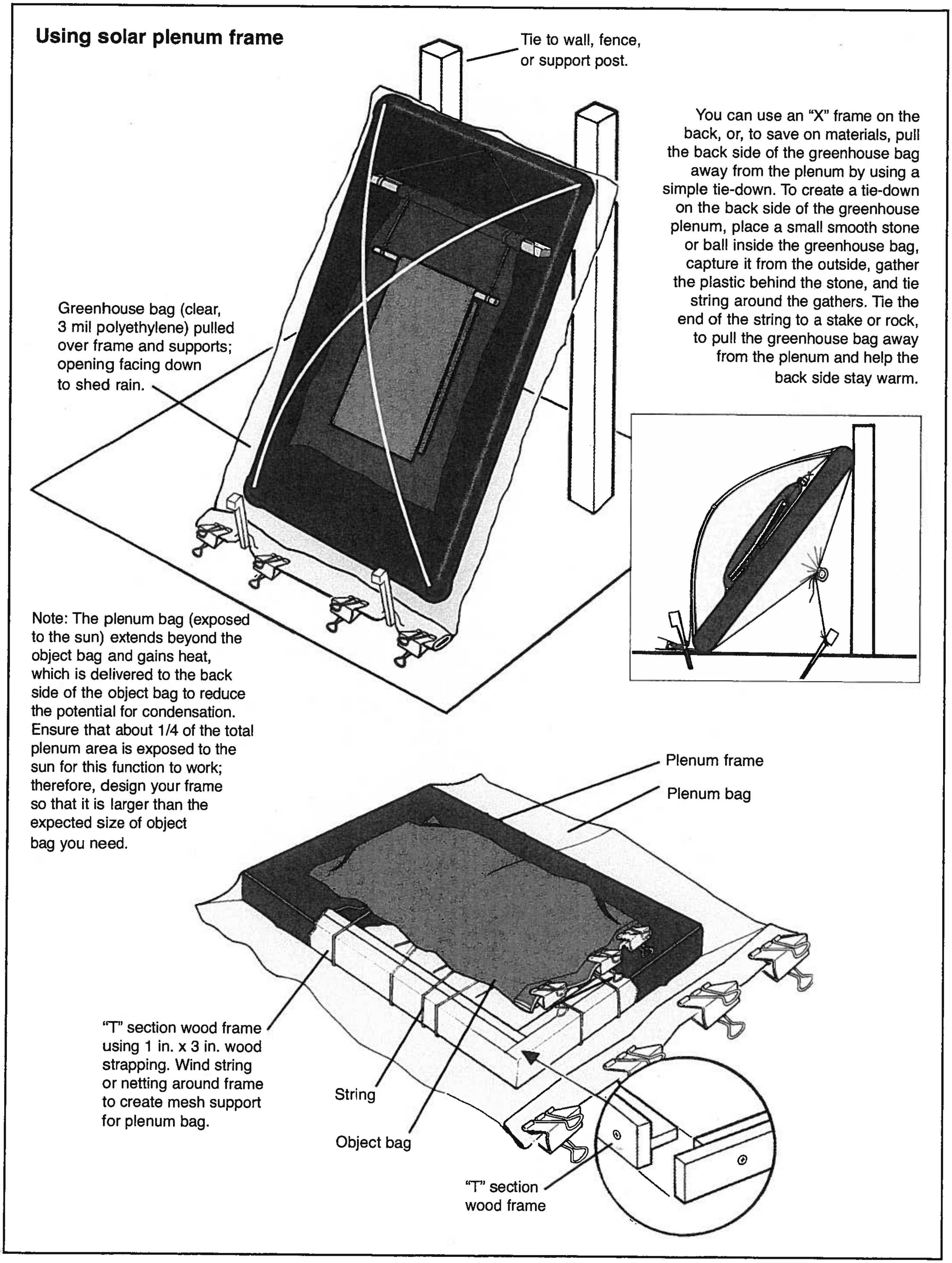


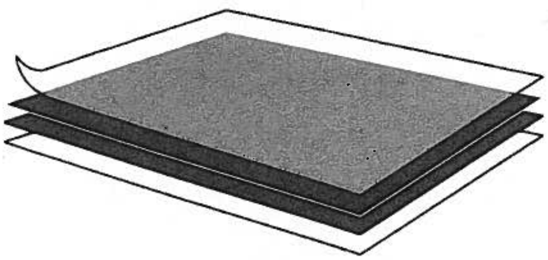

*Figure 19. Solar disinfestation plenum frame (cont.).*

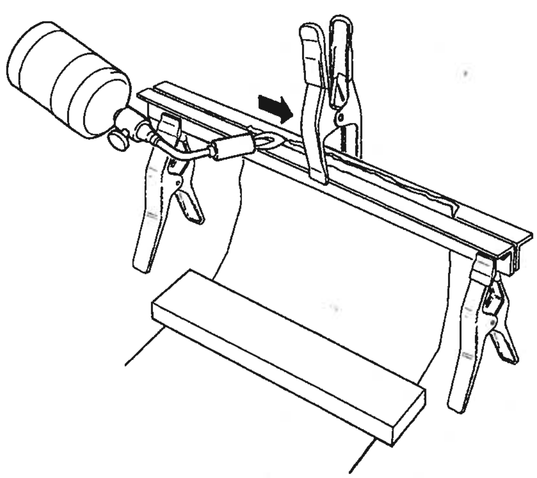
## Solar disinfestation pillow

This arrangement does not require making a rigid frame. Therefore it involves a bit more careful heat sealing than does the plenum frame, but when deflated, the pillow can be stored in a much smaller space. As well, many of these pillows can be easily constructed. It is just as efficient as the plenum frame. However it is vulnerable to windy conditions; therefore, tying a pillow to stakes using a strong line is advised.

Cut four sheets of 3 mil polyethylene, two clear and two black, and stack them as follows: clear – black – black – clear, as illustrated.

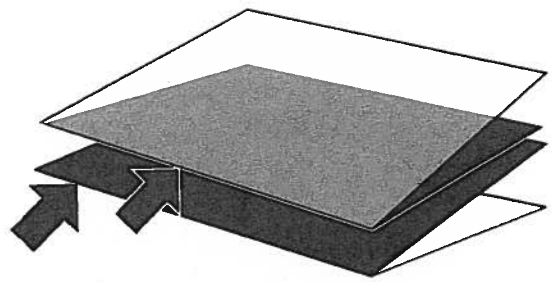
(A doubled layer makes an inflated cavity just below the greenhouse cavity that will smooth out spikes in temperature from solar gain over the object. This starts with a six-layer stack of plastic sheets: clear – black – clear – clear – black – clear. Create additional taped inflation seals inside the object cavity. Slide the object between the two inner clear sheets.)



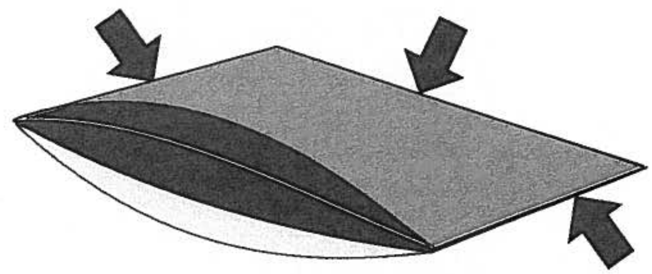


Heat sealing without a specific tool can be done by using two sharp-cornered bars of aluminum angle, a few strong spring clamps, and a small gas torch. Clamp plastic between angles and slice to within 2 mm of the angle bars with sharp scissors. Weigh down loose sheets with planks to prevent them from being lifted by the wind. Quickly pass flame along the protruding edge of plastic until it rolls together. Do this outdoors, away from combustibles, and protect yourself from any plastic fumes. Before removing clamps, ensure the seam is not burning. Properly done, this allows fast assembly of sheet films, and will form a strong bead seam that is airtight.

Heat seal a clear sheet to an adjacent black sheet along one edge for both top and bottom pairs of clear and black sheets.



Heat seal all four sheets together on remaining three edges.



As with the plenum frame, the pillow is oversized so the shady side can heat up (due to transferred radiation that has bypassed the object).

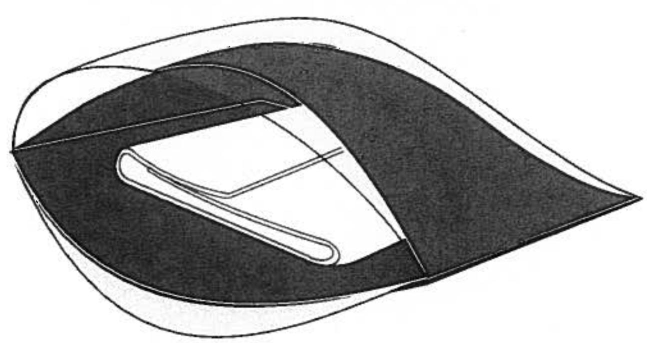
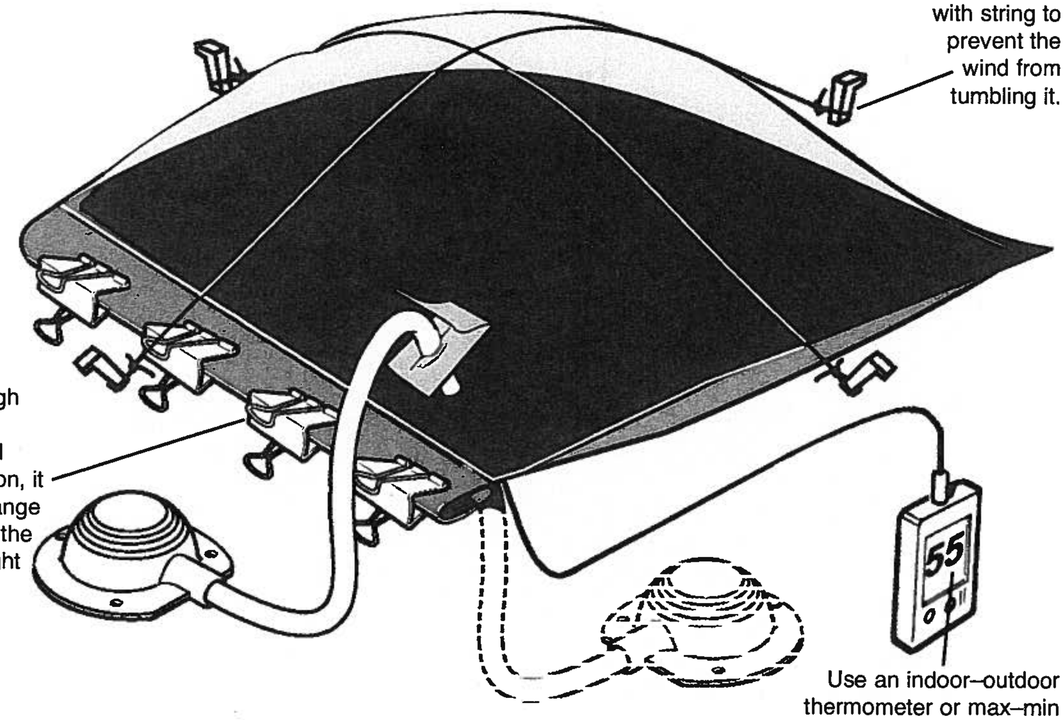
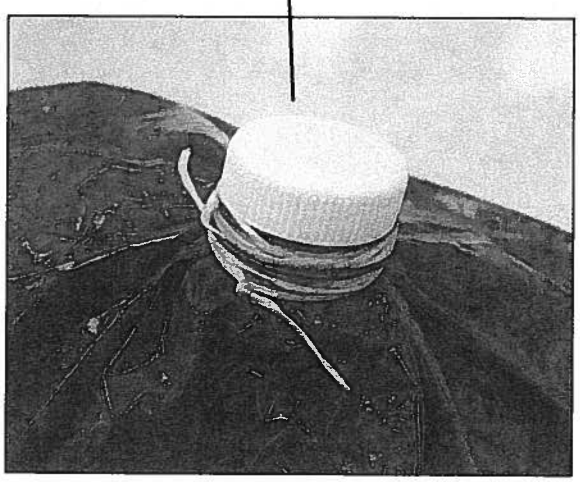


*Figure 20. Solar disinfestation pillow.*

## Inflated solar pillow



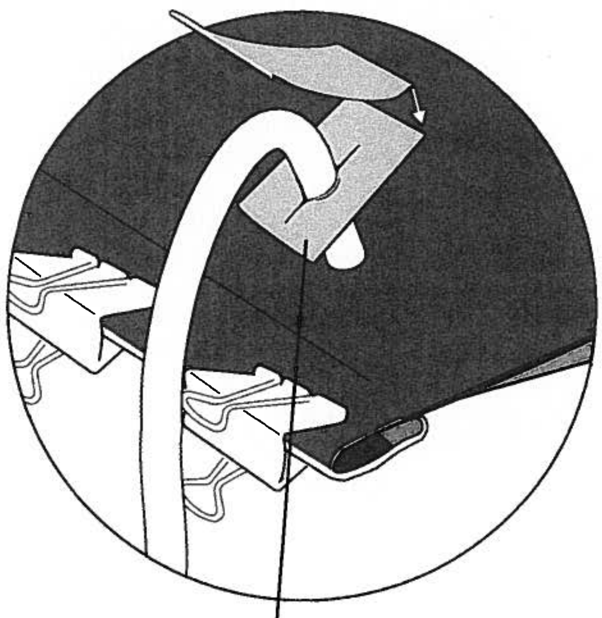




*Figure 20. Solar disinfestation pillow (cont.).*

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## Glossary[3]

*Arthropods* (Arthropodes)
Animals with multi-part bodies, exoskeletons; includes spiders and insects.

*Anoxia* (Anoxie)
A state without oxygen.

*Bacteria* (Bactéries)
Self-dividing single-cell organisms that digest matter. Some can infect other living organisms.

*Bait station* (Point d'appât)
A secure container designed to deliver poison bait to pests (commonly rodents) while protecting other animals and humans from coming into contact with the bait.

*Controlled atmosphere fumigation* (Fumigation sous atmosphère contrôlée)
Altering standard atmospheric gas ratios to kill a living organism by suffocation, desiccation, and disrupted metabolism.

*Disinfestation* (Désinfestation)
The act of killing or removing an infestation.

*EMC* (Degré d'humidité d'équilibre)
Equilibrium moisture content; percentage of object mass that is water after waiting until no mass change is measurable at a specified humidity and temperature.

*Enclosure* (Mise sous enceinte)
The act of enclosing to prevent pests entering or escaping; the physical means of enclosing, by using bags, boxes, jars, vials, or other containers, including buildings; the provision of a degree of separation from the external environment.

*Fumigation* (Fumigation)
Use of a toxic gas or vapour to kill an organism.

*Fungi* (Champignons)
Multicellular organisms that form colonies, characterized by hyphae and spore-forming bodies (e.g. mushrooms, mould).

*Geotextile* (Géotextile)
Engineered fabric or film material to control soil movement or water in soil.

*Hypercarbia* (Hypercarbie)
Elevated concentrations of carbon dioxide gas (greater than 0.03% in Earth atmosphere).

*Insects* (Insectes)
Animals with six legs, an exoskeleton, and three distinct body parts (head, thorax, abdomen).

*Integrated pest management (IPM)* (Lutte intégrée)
A methodology for combining activities to suppress pest damage through knowledge of pest biology, environmental factors, and response technologies, while being compatible with preservation of cultural objects.

3 French terms in parentheses.

*Integument* (Tégument)
Outer shell or exoskeleton of arthropods.

*Microorganisms* (Microorganismes)
"Tiny rascals that rule planet Earth."

*Mould* (Moisissures)
Mono- and multicellular fungi characterized by forming thin mats or distributed colonies over surfaces.

*Oxygen scavenger* (Sorbant)
A chemical substance that is added to an oxygen barrier container in order to remove unwanted oxygen.

*Pest* (Organisme nuisible, parasite)
Something living, but unwanted.

*Pesticide* (Pesticide)
A solid, liquid, or gaseous chemical intended to eliminate a living organism.

*Quarantine* (Quarantaine)
A process of isolation, determination of hazard, and treatment.

*Registered pesticide* (Pesticide homologué)
A compound legal to use as a pesticide in specific jurisdictions, which has known formulation, human toxicity, and efficacy.

*RH* (HR)
Relative humidity; portion of water vapour present divided by the upper limit of water vapour possible at any one temperature.

*Rodent* (Rongeur)
Vertebrate, characterized by permanently growing incisor teeth, e.g. mice, rats.

*Semiochemicals* (Substances sémiochimiques)
Chemicals that alter an organism's behaviour.

*Structural pests* (Ravageurs des structures)
Pests of buildings whose activities affect building strength.

*Symbiosis* (Symbiose)
Beneficial/cooperative living arrangement between organisms, e.g. non-pathological association of microorganisms and insects for digesting food.

*Systematics* (Systématique)
The science of classifying organisms into related groups.

*Thermal control* (Lutte thermique)
Use of low or high temperatures to eliminate a living organism.

*Viruses* (Virus)
Infectious particles containing genetic material that commandeers living cells for their own reproduction.

*Zoonoses* (Zoonoses)
Diseases of non-human origin that cross over to humans in close contact with infected animals or their wastes (e.g. H5N1 avian influenza, hantavirus, rabies, chlamydiosis, histoplasmosis, cryptococcosis).