Housing, Enrichment and Amenity for Rabbits: Technical Standard (H.E.A.R.T. Standard)

A specification of minimum humane requirements for external accommodation of domestic rabbits (*Oryctolagus cuniculus*)

Issue 2.2, February 2017

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Purpose:

To define a set of minimum physical specifications for rabbit housing that can be scientifically demonstrated to be compliant with the requirements of the Animal Welfare Act 2006 section 9. Subsequent application of and compliance with the specifications herein to rabbit housing designs should ensure adequate and humane accommodation and treatment of domestic companion rabbits.

Executive Summary

This specification has been written using information from numerous rabbit and other domestic animal scientific studies, with particular focus on physical, medical and psychological wellbeing. Relevancy to the requirements of the Animal Welfare Act is explained as it relates to the various sections of the act (see below for a breakdown of these "needs"). It will be shown that failure to meet this specification constitutes a breach of the Animal Welfare Act 2006 for both owners of rabbits, and for retailers of sub-standard and/or inhumane housing. For each of the needs relating to rabbit housing, a factual specification will be summarised, with references to source materials and their quotes, and/or experimental data attained as part of this report. A grading system of specifications and features is given for the purpose of assessing the suitability of individual enclosure designs.

Introduction

Rabbits were first introduced into the UK as a domesticated species in the 12th century as a source of meat production (Veale, 1957). These rabbits were kept in hutches similar to those sold today in pet shops for the purpose of keeping them alive and fresh just before they were killed and eaten. Around the time of the 19th century Victorian Britain, the hobby of breeding rabbits as pets began to become popular. Partly as a result of urbanisation of the population, hutches were a convenient and compact method for keeping rabbits in urban areas.

Nowadays much more is known about rabbit welfare requirements, however the hutches that were originally designed for rabbit meat storage are still widely associated with and bought for domestic companion rabbits. The reasons for this can vary from apathy to common misconception to lack of education. Surveys have shown that for areas such as environment, diet, behaviour and companionship, between 90-94% of owners say that they "feel well informed" about the needs of their pets. Given that 57% of rabbits live alone, 29% live on a diet of mainly muesli, only 49% play with toys on a regular basis (PDSA, 2015), and 20% live in housing smaller than the legal requirement for laboratory rabbits (Rooney, et al., 2014), clearly there needs to be more action to prevent mistreatment, accidental or otherwise.

Part of the problem exists because prospective owners are not fully aware of the financial costs of keeping and caring for rabbits. According to the RSPCA, the average pair of domestic rabbits will cost the owner (for all essentials including food, vets bills and accommodation) approximately £16,000 over 10 years. According to the PDSA PAW report, less than 1% of owners surveyed correctly estimated a cost of over £10,000 (PDSA, 2015).

The RSPCA in 2012 also suggested that owners of two outdoor rabbits should spend at least £350 on suitable accommodation. Adjusted for inflation, this is equivalent to £379 in 2016 (Bank of England, n.d.)

Furthermore, just over a third of calls to the RSPCA about incidents of cruelty or neglect to domestic rabbits relate to concerns about inappropriate accommodation (RSPCA, n.d.). Clearly something has to change.

Some rabbit housing manufacturers, retailers and welfare associations have attempted to address the problem, however they are hindered by the overwhelming proliferation of cheap, inadequate housing that 97% of veterinary professionals believe should be banned from sale (PDSA, 2015).

Contained within this report is a large range of scientific facts about rabbit physical health, psychology and mental health, safety and security, and behavioural patterns that demonstrate how a rabbit housing should be designed in accordance with the requirements of the Animal Welfare Act 2006. It is hoped that any accommodation that does not comply with this specification be deemed unsuitable, and therefore by definition should not be permissible to buy, sell or trade within the UK.

Acknowledgements

This report is dedicated to Wiggles and BoBo, two adorable rabbits whose happiness and wellbeing inspired and drove the author's determination to improve the lives of all domestic rabbits.

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Units

^{0}C : Temperature in degrees Celsius/centigrade
m^2 : Area in square metres
STC: Sound transmission class (ratio)
BTU: British thermal units (heat output)
cm: Distance in centimetres
N: Force measured in Newtons
PSI: Pressure in pounds per square inch

"Five Needs" as required by the AWA 2006 section 9

Part (2)

(a) its [the rabbit's] need for a suitable environment,
(b) its [the rabbit's] need for a suitable diet,
(c) its [the rabbit's] need to be able to exhibit normal behaviour patterns,
(d) any need it [the rabbit] has to be housed with, or apart from, other animals, and
(e) its [the rabbit's] need to be protected from pain, suffering, injury and disease
(UK Government, 2006)

Definitions

For the purpose of this specification, the wording from the AWA2006 will mean the following:

a) Somewhere suitable to live:
"suitable", adjective (Oxford Dictionaries, n.d.) meaning "acceptable or right for someone or something". In the context of living accommodation for rabbits, this will mean an environment that allows the animal access to all the areas of resource that it requires "Resource" meaning; food, social interaction, enrichment, mental wellbeing and exercise. This section relates strongly to section 5 regarding protection from illness or injury.
It should be noted that because this report is focused on suitable housing, this need requirement will encompass aspects of needs (c), (d) and (e).

b) Proper diet and fresh water:
As this specification is directly related to housing, need (b) will not be covered in much detail.

c) Ability to express normal behaviour:
"normal", adjective (Oxford Dictionaries, n.d.) meaning "ordinary or usual; the same as would be expected". In the context of rabbit behaviour, this will mean innate behaviour consistent with an animal not being negatively affected by the circumstances of its captivity.

d) Be housed with or without other animals:
"Being housed with another animal" in this context will be defined as having regular unrestricted (by humans) access to physical, visual, auditory and olfactory interaction with another rabbit.

e) Protection from, and treatment of, illness or injury:
"Protection from illness or injury" will in this context be defined as both physical protection from predators and the environment, and from mental and physical illness caused by lack of exercise, enrichment, safe spaces, and expressions of normal behaviour that are covered in need (c). Treatment of illness or injury will not be covered in much detail as it is beyond the scope of this specification.

Scope of Specifications

Need (a): Somewhere suitable to live

Based on the information acquired by decades of research into what constitutes a "suitable" place to live, this section will cover the following categories:
1) Minimum footprint
2) Minimum height
3) Safe materials
4) Thermal insulation
5) Sound insulation

Need (c): Ability to express normal behaviour

The natural and biological needs of rabbits to express normal behaviour are widely accepted as essential by the scientific and animal welfare community. The effect of inadequate housing, meaning spatial restriction, access restriction, and interaction restriction, has been widely studied, e.g. (Dixon, et al., 2010), and can be demonstrated as a major factor in abnormal and detrimental behaviour.

The effect of inadequate housing on the following innate behaviours will be demonstrated:

1) Exercise
2) Expressions of happiness and/or excitement
3) Social behaviour
4) Comfort activities
5) Environmental interaction
6) Motivation

Need (d): Be housed with or without other animals

In the context of rabbits, it will be demonstrated beyond a reasonable doubt that it is essential for rabbit welfare for them to be housed in a minimum of a pair, and in doing so will demonstrate that keeping them separate is in violation of the Animal Welfare Act. Further to this, given the minimum space requirements for a single rabbit, the sale of any housing that does not meet the minimum size requirements for two rabbits will be considered inhumane and in violation of need (a) (somewhere suitable to live).
Based on the literature, the following can be reasonably demonstrated:

1) Rabbits consider social interaction with other rabbits almost as important as food.
2) Rabbits that are housed singly are more likely to develop behavioural problems.
3) Housing that does not accommodate more than one rabbit can create severe distress.

Need (e): Protection from, and treatment of, illness or injury.

In the context of housing, protection from illness or injury rather than treatment will be the focus of this document with regards to need (e). There are numerous factors relating housing to protection from illness and/or injury. It will be demonstrated both factually and practically that adequate protection can be achieved by setting a minimum requirement both in terms of security from predators, and access to appropriate living, exercise, "bolt-hole" and enrichment areas.

The areas that will be demonstrated as necessary to ensure protection from illness or injury are:

1) Physical resistance to fox attacks
    a. Strength of locks and fixings
    b. Strength of mesh
    c. Mesh fixings
    d. Framework integrity
2) Prevention of bird of prey/ aggressive bird attacks
    a. Provision of a solid/mesh roof
3) Provision of hiding places
4) Separation from another aggressive rabbit
5) Environment induced illness
    a. Hypothermia
    b. Lack of exposure to UV light creating vitamin D deficiency
6) The absence of exercise areas and environmental enrichment is detrimental to physical and mental health.
    a. Obesity
    b. Sense of safety
7) Trimming/covering of plastic components and edges

8) Entrapment prevention

Need (a):, "its need for a suitable environment"

When specifying what constitutes a suitable place to live, consideration should be given to the fact that rabbits have not naturally evolved to be domesticated animals, rather have been selectively bred either for the purpose of meat production or for aesthetic reasons (Carneiro, et al., 2011), and even the most generous domestic accommodation will likely never approach the approximately 2185m^2 of space that is enjoyed by the average wild male rabbit (Myers & Poole, 1961). Given the limitations imposed by the availability of land in the UK, and the practicality of such large enclosures, this chapter will focus on the minimum spatial and environmental aspects of a domestic rabbit enclosure that will prevent any observable negative physical and mental wellbeing.

Minimum footprint

The minimum footprint (floor area), is determined by several factors; the minimum space required to display "normal" behaviour, the space required to run and exercise, and the space required for at least two rabbits.

In terms of space required for physical activity, hopping, running and laying outstretched are all innate behaviour, and therefore must not be restricted. It has been shown that rabbits kept in small enclosures are not able to exhibit normal behaviour (Rooney, et al., 2014). This is discussed further in the chapter on normal behaviour.

The need for a minimum allowable footprint is further emphasised by the fact that approximately 20% of the UK companion rabbit population live in hutches smaller than 0.54m^2 (Rooney, et al., 2014), which is smaller than the legal requirement for laboratory rabbits. (Home Office, 1989)

Research into the effects of spatial restriction on rabbit behaviour has shown that enclosures less than 1.68m^2 per rabbit have a negative effect on behaviour, particularly in terms of the rabbit's propensity to be active, to interact with their environment, and to display other normal behaviour such as rearing up (Dixon, et al., 2010).

Given the need for rabbits to run within their enclosure, the need to house rabbits in a minimum of a pair (discussed later) and taking the definition of "run" to be at least three hops (Morton DB & M, 1993), equating to approximately 1.8 metres, for a 3.35m^2 total area, the minimum overall dimensions will be 1.8 metres by 1.8 metres for a pair of rabbits. These dimensions should increase proportionately depending on how many rabbits the enclosure is designed for (minimum of two).

The same study showed that the larger the enclosure, the more active the rabbit, therefore the minimum area of 1.68m^2 should be considered an absolute bare minimum. Enclosures of twice the size (3.35m^2 per rabbit) showed an increase in activity, so should be considered more ideal.

Minimum height

Previous research has shown that rabbits sit and rear more in pens 75 cm high or with no ceilings, and the average height needed to fully 'rear-up' is 52.6 cm (Dixon, et al., 2010). In light of this, despite 52.6cm

being required for the average rabbit to fully rear up, the fact that research shows that 75cm is required to do so comfortably (as they would do were they not in captivity), a suitable enclosure would have a minimum height of 75cm.

Figure 1: A rabbit standing on its hind legs

Rabbits can also jump up to 100cm high (Guiness World Records, 1997) (height of paws from the ground), so an enclosure with a run that is 120cm tall or more would be more ideal.

Figure 2: Rabbits can jump as high as 95cm (photo credit: sv:User.Wikkie)

Adequate materials

Information on the effect of materials on rabbit health is discussed in Need (e).

Not all timbers are created equal. There are many different types of timber used in construction of everything from houses to boats to bridges to rabbit housing. Unfortunately, the cheapest timber is also the softest, quickest grown and not pressure treated. On the other end of the spectrum the best timber is dense, slow-grown, and fully pressure treated after it is cut. While these elements of timber may be seen as purely a quality vs cost component, they are essential to providing a safe, secure and durable enclosure. Timber that is soft and slow grown will be easily gnawed by a rabbit in a matter of weeks, resulting in compromised structural integrity and security. Likewise, timber that is not properly treated will rot, degrade, and result in structural failure either as a result of weathering or predator attack.

Figure 3: Rotten timber, as shown above, will weaken the structure and attached mesh leaving rabbits vulnerable to attack. (photo credit: Beentree)

Figure 4 some soft timbers, while resisting a simulated fox attack, are easily damaged

Figure 5: Denser slow grown timbers are more resitant to simulated attack

Thermal insulation

A temperature of between 10-20°C is recommended as ideal for domestic rabbits, though they can cope with lower temperatures, but tend to suffer from too much heat. Rabbits can cope with the cold fairly well, but not if they are housed in damp or draughty conditions. Being cold and wet can lead to your rabbit becoming ill and could be fatal if action is not taken. Older rabbits can suffer from painful arthritis, so need to be kept warm and dry. Rabbits that are thin, young or do not have a thick winter coat may also need special attention to ensure they keep warm and dry. (RSPCA, Companion Animals Department, n.d.)

The natural dwelling of a wild rabbit during rest and sleep periods is in an underground warren. This allows the animal to maintain a comfortable temperature and not be in contact with cold surfaces, which can cause hypothermia. The conventional "solutions" to cold weather effects on outdoor housed rabbits include supplying extra bedding materials or fitting an "insulated" hutch cover. Due to the fact that most domestic outdoor hutches are raised off of the ground to prevent damp, their exposure to cold air results in surface temperatures not sufficiently higher than the ambient atmospheric.

"U–value: a measure of the heat transmission through a building part (as a wall or window) or a given thickness of a material (as insulation) with lower numbers indicating better insulating properties" (Merriam-Webster Dictionary, n.d.)

The U-value of any structure, whether it is a family home, vehicle, or rabbit housing, is the coefficient that describes how well the structure retains heat. It is calculated using the thermal transmittance values of the materials used in the construction of the walls, as well as the heat output of any relevant heat sources (in this case, the body heat of an average pair of rabbits).

For the purpose of this specification, an average rabbit will weigh 2kg, and the heat output will be calculated in BTU/Hr from the formula $H = 6.6\ m^{0.75}$ (Engineering Toolbox, n.d.). This gives an approximate heat output for two average resting rabbits of 40 BTU/Hr, equivalent to 11.75 Watts.

As the average minimum air temperature in England is 1.3 degrees in January (Met Office), and the surfaces of a rabbit's natural warren at a depth of 2m will be approximately 7^0C (British Geological Society, n.d.) , insulation coupled with the body heat of a minimum of two rabbits should be sufficient to raise the ambient temperature by a minimum of 6^0C.

For a sleeping area, approximately 4ft long x 2ft wide x 2ft tall, this equates to a maximum U value of approximately 1.5

Similarly, since rabbits do not cope well in high temperatures, such as those above the England average July temperature of 20.9^0C, the enclosure should be designed to help reduce the likelihood of the rabbits

enduring dangerously high temperatures during normal climatic conditions. This can include but not limited to; covering the sleeping area in material to reflect direct sunlight and infrared radiation, fitting or designing in ventilation features or components, and not using transparent materials what create a greenhouse effect. During abnormal atmospheric conditions (e.g. heatwaves), should the temperature inside the sleeping area reach a level that can pose a risk to the rabbit's health, it should be immediately taken by the owner to an alternative safe and cool area. According to a study conducted by a rabbit rescue (CottonTails Rescue, Wiltshire, UK), approximately 1% of premature rabbit deaths are caused by heat exhaustion. While this percentage is low, it represents up to one thousand domestic rabbit deaths per year.

Figure 6: An exploded view of an example of a fully insulated sleeping area

Sound insulation

A large proportion, 58 per cent, of rabbits are thought to be fearful of loud noises (Rooney, et al., 2014)

Given that a rabbit's natural habitat is underground, and therefore insulated from loud noises, to prevent distress a domestic outdoor enclosure should provide auditory protection from sources of noise such as fireworks, dogs barking, garden appliances (e.g. lawn mowers), and other typical sources of domestic noise. There is currently no data available to indicate what specific level of sudden noise is acceptable for rabbits. Further study is needed to adequately determine specific requirements for noise reduction to prevent sudden distress, however there is literature on long term exposure (see below), and also the effect of specific sudden noises.

Given that around 3% of rabbit deaths are caused by shock from fireworks (around 3,000 rabbits every year) (Cottontails Rescue, n.d.), the need for sound reduction is clear.

The most common source of loud noises that are responsible for rabbit deaths are fireworks and dog barking (Cottontails Rescue, n.d.). The cause of death can be as a result of cardiac arrest (heart attack), or audiogenic seizure (Turner, et al., 2005) The highest energy frequencies from fireworks occur in the 125, 250 and 500Hz bands (Tingay, 2011), and the loudest dog barks are in the 400 to 700Hz range (Averbuch, et al., n.d.). Sonic bangs from low flying aircraft have been shown to cause drastic behavioural abnormalities, particularly linked to reproductive and maternal activity, including the killing of a rabbit's young (Broucek, 2014). Traumatic injuries from startled responses to the limbs and back have also been observed (Marai & Rashwan, 2004).

Exposure to consistent background noise of 80-dB or more has been shown to cause fear in rats, and sleep deprivation in rabbits, while moderate noise levels above 85-dB have been linked to elevated cholesterol and athercosclerosis (arterial disease). Elevated noise levels amongst laboratory animals have also been known

to cause disorders such as hypertension, altered immune and healing response, termination of pregnancy, and reduced body weight.

Figure 7: Transmission losses of 25dBA at 160Hz are achievable with insulated walls

Road noise is one of the most common sources of noise pollution, being created by friction between tyres and the road as well as aerodynamic noise and engine noise. Studies have shown that the most prominent frequency for road noise is 1000Hz (Sandberg, 2003)

Given the projected increase in population density in the UK (Office for National Statistics, 2015), and the increase in noise pollution (Office For National Statistics, 2007) the need for adequate noise protection for rabbits must be addressed.

Figure 8: Thin timber walls offer little noise reduction, transmission losses of 5 decibels at 160Hz will not prevent distress and other adverse health effects

Sound reduction levels are normally measured experimentally and are quantified using the STC (sound transmission class). However, this rating system includes frequencies much higher than those associated with health issues in rabbits. For the purpose of determining the sound insulation suitability for rabbits, the frequencies associated with fireworks, dog barking and noise pollution are of most importance and will be assessed. Appendix 7 details the testing methodology of the sound insulation.

Need (c) "its need to be able to exhibit normal behaviour patterns"

"Rabbits are often confined in unsuitable hutches, something that can deprive them of the opportunity to behave naturally. Physically, a following frustration might lead to digestive ailments and diseases. While mental stress may result in apathy and depression. Rabbits unable to be active or to experience pleasure will inevitably spend much of their time sitting still. What else is there to do? Such apathy may well be explained by learned helplessness, a term in psychology explaining when animals learn that they cannot influence the situation. Experiencing a lack of control might lead to the apparent failure to respond in future situations. The rabbit knows it can't escape or fight the scary hands picking it up and will just sit quietly. However, a passive and lethargic rabbit is not a cheerful rabbit. They should be investigating, be curious, active and alert, they should dig and chew, jump, run at full speed and throw themselves on their side in total relaxation." (Schepers, 2009)

"It has been argued that domestic rabbits are well suited to live in small enclosures that are usually provided to rabbits reared for meat, for laboratory use, or as companion animals (Princz et al., 2008;

Negretti et al., unpublished data). Similarly, activities such as vigilance and foraging may be unnecessary for captive rabbits with an adequate diet and removal of predatory cues, yet McBride (1986) found that domestic rabbits in indoor pens spent 12% of their time in alert behaviours. Other studies of domestic rabbits in farmed and laboratory conditions have found that providing additional resources, space, and companionship allows a more varied behavioural repertoire. For example, group-housed rabbits which are reared for meat and are kept in 1.6 m2 enclosures maintain a behavioural repertoire comparable with that of wild rabbits, whereas group-housed rabbits kept in 0.4 m2 enclosures performed a more limited range of behaviours generally seen in wild rabbits (e.g., Martrenchar et al., 2001)." (Dixon, et al., 2010)

Exercise (24 Hour access)

The need for a rabbit to exercise is vital, not only for their physical health but also for their mental health. Many owners believe that restricting their rabbits' access to the exercise area during certain times of the day, either for practical reasons or because their only exercise area is a garden, does not have any effect on the rabbit's wellbeing. However, studies have shown that a rabbit requires unrestricted access to their exercise area at all times, and that restricting access results in lower motivation to exercise, which can lead to physical health problems. (SHIRLEY C. SEAMAN*, 2006). This requirement is further emphasised by the various codes of practice and welfare publications

Expressions of happiness, comfort and/or excitement

Behaviours like binkying, rearing up and lying stretched out may be prevented in some living environments (e.g. due to inadequate space or height) (Rooney, et al., 2014)

Figure 9 : A rabbit displaying "binkying" as a sign of happiness or excitement (photo credit: James Pockele)

Social behaviour

The need for social behaviour is not only met by housing of two or more rabbits together. Factors arising from housing size, layout and features also have a large effect on a rabbit's propensity to exhibit normal social behaviour (Dixon, et al., 2010).

Separate spaces

Rabbits housed together, even bonded pairs and groups, will on occasion require separate spaces if an altercation over food or territory arises, or due to hormone imbalance caused by changes in environment, dietary changes or other influences. An enclosure should always include provisions for rabbits to retreat to a separate space, ideally enclosed on at least three sides that partition the area.

Environmental interaction

Digging, running and playing are all essential activities for rabbits to display on a daily basis.

According to the Peoples Dispensary for Sick Animals, only 24% of domestic rabbits get the opportunity to dig on a daily basis, despite it being an important natural behaviour. (PDSA, 2015)

Making provisions for a rabbit to dig within an enclosure can be problematic from a design perspective, since many owners prefer to mount their enclosures on solid ground to prevent escape, and also to prevent predator incursion. This is beyond the control of the enclosure manufacturer, however the manufacture of solid-floored enclosures should advise that internal digging enrichment (e.g. a soil box) is required for normal expression of behaviour.

Rabbits also show behavioural preferences for enclosed areas, so lack of tunnels and denning areas have shown to be in some cases a welfare concern (Rooney, et al., 2014). Provision of these features as an addition to the basic hiding places discussed later would be considered ideal.

Motivation

Inadequately sized enclosures have a detrimental effect on motivation to perform normal activities, which can lead to secondary physical and mental disorders.

High levels of inactivity found in smaller pens may be the result of the restricted environment, limiting the number of behaviour patterns that could be performed physically and has been related to emotional states such as ''frustration'' (Wiepkema, 1985)

The same study that assessed a rabbit's motivation for social interaction also found that they were highly motivated to be nearby a platform. The exact reason behind this is uncertain as in the study they rarely used it, suggesting that it may serve primarily as a "bolt-hole" function. (SHIRLEY C. SEAMAN*, 2006)

Interaction with humans

The design of housing is not necessarily primarily concerned with the interaction of rabbits with their owners, as this is something normally instigated by and controlled by the owner. However, it should be noted that many rabbit enclosures permit access to the exercise and sleeping areas via a removable or lift up panel above where the rabbit is located. As rabbits are naturally a prey species, this method of approach mimics what rabbits instinctively interpret as prey behaviour, which can lead to fear related stress disorders (Fry, n.d.). Therefore, access to a rabbit's exercise and sleeping area should be from the side.

Need (d) "any need it has to be housed with, or apart from, other animals,"

Rabbits are not solitary animals. Their need for companionship with another rabbit is almost as essential as the need for food. (SHIRLEY C. SEAMAN*, 2006) It also appears that solitary housing in general reduces the rabbit's lifespan. (Schepers, 2009). Despite the facts proving the fundamental need for rabbits to be housed in a minimum of a pair, approximately 60% of

the UK companion rabbit population lives alone.

1) Rabbits that are housed singly are more likely to develop behavioural problems (Dixon, et al., 2010)
2) Housing that does not accommodate more than one rabbit can create severe distress. (Dixon, et al., 2010)

Given the need to be housed with at least one other rabbit, the minimum dimensions mentioned earlier (Dixon, et al., 2010) should be increased proportionately depending on how many rabbits the accommodation is designed for.
As the minimum enclosure area (excluding isolated sleeping area) for a pair of rabbits is 3.35m^2, and given that the level of lethargy and sedentary behaviour increases with 50% smaller enclosures, enclosures designed for two rabbits (minimum) should be 50% larger (1.68m^2), as a portion of the original 3.35m increasing linearly by 1.68m^2 for each additional rabbit. It should be noted that for each additional rabbit that the enclosure is designed for, additional safe spaces and platforms must be included also.

Figure 10: Rabbits housed in a minimum of two, with provision for steps and hiding places

Need (e) "its need to be protected from pain, suffering, injury and disease"

A survey conducted by a British rabbit rescue into the causes of premature death identified the following: (Cottontails Rescue, n.d.)

23% teeth related problems
17% digestive upset
10% parasitical/bacterial infection
8% unknown short term illness
7% killed by fox
7% respiratory infection;
6% cancer;
6% sudden death with no symptoms
3% died under anaesthetic;
3% shock from fireworks;
2% kidney failure;
2% myxomatosis;
2% flystrike;
1% poisoned;
1% heat exhaustion;
1% accidental injury;
1% escaped and assumed dead

While it is uncertain how many of these specific cases were directly or indirectly related to housing inadequacies, almost all of the causes of death can be reasonably assumed to be potentially resultant from housing issues, and must therefore be considered a risk to be mitigated.

For example, teeth related problems could be caused by chewing on soft timber that contains nails or staples. Digestive upset, respiratory infection, cancer, kidney failure and poisoning could be caused by toxic chemicals in wood treatment or construction materials. Parasitic/ bacterial infection, myxomatosis, and flystrike could be as a result of lack of

provision for hygiene (e.g. not possible to clean). Killed by fox could be as a result of inadequate wire mesh or timber joins. Shock from fireworks is very likely due to lack of sound insulation. And heat exhaustion is likely caused by lack of protection from the sun and/or extreme temperature. As for "unknown short term illness" and "sudden death with no symptoms", these could possibly be the result of hypothermia, poisoning, shock or any number of causes that leave no obvious signs.

Physical resistance to fox attacks

The primary aspects of adequate fox attack protection are:

- Strength of locks and fixings
- Strength of mesh
- Mesh fixings
- Framework integrity

Protection from attack or aggression from potential predators. According to a survey done by an animal rescue (Cottontails Rescue, n.d.) attacks by foxes account for between 7% (proven cause) and 13% (including potential cause from "sudden death with no symptoms") of premature deaths in rabbits. Given that there are approximately 1.2 million rabbits in the UK, and assuming a static population, this means that between approximately 7,000 and 13,000 pet rabbits are killed every year by foxes. It has been estimated that in the UK, depending on the season there are between 252,000 and 504,000 foxes, and they are more densely populated in urban areas (Stephen Harris, 1995).

Figure 11: Foxes are capable of climbing practically any domestic structures

Figure 12: Foxes are everywhere. In February 2011, a fox was found living on the 72nd floor in the part-built "Shard" skyscraper in London (photo credit: George Rex Photography)

Rabbit enclosures are also occasionally attacked by other predators such as cats, badgers, and birds of prey (and also sometimes non-predatory birds), however given the fox's ability to climb, jump, gnaw and pull, it represents the most serious threat to rabbits in their enclosures.

Treating the fox as by far the most likely natural predator, the housing design needs to demonstrate that it is strong enough to withstand a prolonged attack.

Data collection from various force measurements on the mechanics of fox attacks has shown the following:

1) Fully grown foxes can apply a bite force of up to 145N on the anterior incisors, and up to 240N on the posterior molars. (Christiansen & Wroe, 2007) The materials used in the construction of an enclosure need to be able to withstand a prolonged attack of this nature.

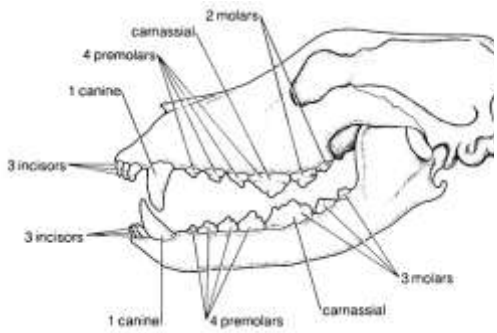


Figure 13: European Red Fox Skull and dental layout

2) The average European red fox can use their teeth to pull on mesh and timber frames with a force greater than 185N (see appendix 1). The structure of an enclosure and the fixings used need to be able to withstand a prolonged attack of this nature.
3)
4) Fully grown foxes can jump up to 1 metre high (60cm at the paws), and use their front paws to break into enclosures. Given that the average weight of an adult fox is 8kg, this equates to a total kinetic energy of approximately 490 Joules and a pressure of 1160 PSI (see Appendix 3). The roof structure of an enclosure needs to be able to withstand these pressures.

Figure 14: Foxes can break through tough barriers to reach their prey (photo credit: Mike Baird)

Foxes are very determined animals, and the prospect of an easy meal (one that is confined in an enclosure), often results in prolonged and repeated entry attempts via all potential methods of access. From recordings of night-time fox attacks, it can be seen that they will often attempt entry via what they perceive as the weakest point of an enclosure, or if they can sense a rabbit on the other side of a door. Given the nature of such attacks, the hinges, locks, mesh, and framework all need designing and testing to ensure adequate protection. Details of how these tests are conducted is covered in appendices 2, 3 and 4.

Figure 15: This 21 gauge (0.8mm) 25mm aperture galvanised weld mesh quickly failed in a matter of seconds during a simulated fox attack

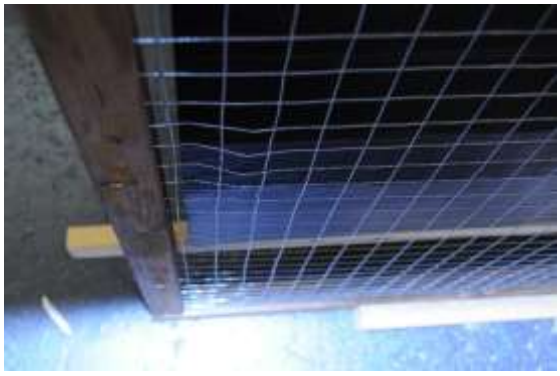


Figure 16: This 19 gauge (1.1mm thick) 25mm aperture galvanised weld mesh, while distorting and bending noticeably, did survive a simulated fox attack.

Figure 17: Chicken wire is particularly weak when subjected to simulated fox attacks, lasting mere seconds

Figure 18 . Meshes fixed using only staples will also fail after only a few minutes

Figure 19: This 17 gauge weld mesh secured with trims is seemingly untouched after a prolonged simulated fox attack

Figure 20: Some soft timbers, while resisting a simulated fox attack, are easily damaged

Figure 21: Denser slow grown timbers are more resitant to simulated attack

<u>Prevention of bird of prey/ aggressive bird attacks</u>

There are many wildlife information resources (e.g. wildlifeonline.me.uk), that offer advice on the best fence design (e.g. height, overhang etc.) to protect domestic pets from fox attack. While this may be sufficient to protect rabbits from

land based animals, it does not give adequate protection from bird attacks.
Predatory birds that exist in the UK that are a threat to rabbits include hawks, sparrows (using rabbits as a source of fur for nest building), owls, falcons, and kestrels. Due to the risk posed by predatory birds, adequate rabbit housing should include a solid roof, either from timber or weld mesh. It should be noted that clear plastic or glass should not be used as a roofing material as this will generate a greenhouse effect.

Figure 22: Rabbits in enclosures without roofs can easily be taken by predatory birds (photo credit: Rhys A.)

Provision of hiding places

There should always be at least as many hiding places as there are rabbits. In addition to the need for separate spaces arising from social interaction issues, hiding places from external predators and/or aggressive companions must be provided. (Welsh Assembly Government, 2009)

Figure 23: A rabbit making use of an incorporated hiding place

Environment induced illness

Hypothermia

While rabbits are capable of tolerating colder temperatures, like most mammals they are susceptible to illness and even death if their core body temperature drops too low. While the rabbit's fur helps to insulate its body, the fur does not repel water very well or dry out very quickly. A rabbit whose fur coat is saturated with water, in cold temperatures, will quickly begin to display signs of hypothermia (RSPCA, Companion Animals Department, n.d.).

Vitamin deficiency

Up to a third of UK rabbits are kept indoors. While there are obvious benefits to this, if not properly managed it can lead to serious medical problems. Lack of exposure to UV light results in vitamin D deficiency. While rabbits benefit from periodic exposure to UV light, they do not always fare too well in direct sunlight (Welsh Assembly Government, 2009). A suitable rabbit enclosure should comprise of a shelter that provides both sufficient shelter from the rain and direct sunlight, but also allow sufficient UV exposure to prevent illness. It should be noted that exposure to UV light does not require direct sunlight. (Animal Welfare Foundation, 2012)
It is important to note that from April 2002, all new domestic double glazed windows do not permit UV light transmission.

Lack of exercise

The need for steps

Rabbits are very active, athletic animals. To exercise appropriately, they must be

able to crawl, hop and run about. Jumping on and off raised areas, such as appropriate sturdy platforms or hay bales, helps rabbits maintain their bone and muscle strength. If your rabbit does not have enough exercise, its bones can become weak and break; this can happen even if your rabbit simply struggles when you pick it up (Welsh Assembly Government, 2009)

A study conducted by the University of Bristol and BioMed Central found that platforms can encourage rearing and climbing and possibly improve musculoskeletal fitness, but 34.1% of rabbits were not provided with such devices. Large numbers of the surveyed rabbits would therefore be unable to rear regularly and consequent musculoskeletal health problems may arise (Rooney, et al., 2014).

The need for steps to serve as a "bolt-to location is mentioned earlier in this report.

Figure 24: A rabbit enclosure featuring a step into the sleeping area

Obesity

Larger pens do increase activity levels which help decrease in activity related problems such as obesity (e.g., ichinoseki-Sekine et al., 2009) and bone injuries or deformities (Drescher, 1992). Thus, access to a larger enclosure where increased activity can be performed would improve pet rabbit welfare.

Musculoskeletal

Spatial restrictions that influence the execution of behaviour are generally thought to cause frustration and have an effect on welfare (Morgan, 2007). In rabbits, however, restriction of natural movement has also been shown to cause permanent abnormalities of the skeleton (Drescher, 1992)

Gastrointestinal

There are many aspects of housing that can directly result in loss of gastrointestinal motility (World Small Animal Veterinary Congress, 2008), these include:

- Proximity of predators
- Extremes of weather/temperature
- Ingestion of toxins (e.g. lead)
- Sudden change of housing

Safe materials

Many materials used in the construction of conventional rabbit enclosures are not covered by regulations governing toxicity and other adverse health effects. However, just as with humans, if a rabbit were to consume even small amounts of the material comprising its housing, there is a risk of illness or even death.

Timber

As mentioned in Need (a), not all types of timber are suitable for rabbit housing. Whereas soft and untreated timber will degrade and be chewed, other types of timber pose a serious health hazard. Some common timber types that must not be used (BunnyHugga, n.d.):

- Beech
- Birch
- Cedar
- Cherry
- Elm
- Mahogany
- Oak
- Plywood
- Rosewood

Figure 25: This plywood partition wall will result in poisoning if chewed

Plastics

The ingestion of any types of plastic, and indeed any other types of indigestible material such as carpet, can lead to serious digestive diseases.

The most obvious of these is lead poisoning. Prolonged consumption of materials with relatively high lead content can cause several serious health issues (PetMD, n.d.) including:

- Loss of appetite leading to anorexia
- Loss of GI (as mentioned before)
- Blindness
- Weakness, lethargy, ataxia
- Seizures
- Anaemia

Other materials that may contain high lead content:

- Linoleum (lino flooring)
- Cages lined with solder or lead paint
- Lead-based house paint

It is crucial that any exposed edges of material that has the potential to cause illness if ingested are trimmed or covered with a layer of a chew resistant (i.e. not easily chewed), non-toxic material.

Coatings, paints and treatments

Any rabbit housing that is intended for use outside or in areas likely to come into contact with water will require some form of protection against rot, mould and insect infestation. There are several solutions to this. The most durable and simplest solution is to purchase an enclosure that has been pre-pressure treated. This results in the longest lasting protection, and does not require any additional treatment for at least several years. The cheapest solution is to treat bare timber with a store bought timber treatment. There are several brands available which comply with the following requirements:

- Water based
- Free from heavy metals

- Low VOC (volatile organic compounds, e.g. formaldehyde)
- Non-creosote

Treatments need to be water based and free from volatile organic compounds and non-creosote to prevent hydrocarbon toxicosis, which is caused by inhalation, ingestion and skin contact of petroleum based products and can lead to severe and potentially fatal health problems including, but not limited to, vomiting, diarrhoea, breathing difficulty, skin disorders (e.g. blistering) and nervous system disorders.

It is important to note that there are no timber treatments on the market that are entirely 100% safe for rabbits. They all contain at least small quantities of chemicals that if ingested or otherwise absorbed into the body in sufficient quantities can cause significant health problems. Some timber "treatments" are advertised as completely free of toxic substances, however they also do not protect the wood from fungus, algae, moss or similar causes of rot and deterioration.

Poisoning from heavy metals has been discussed earlier with regards to lead content of plastics, however other heavy metal compounds such as copper carbonate and chromated copper arsenate (CCA) are sometimes used in wood treatments. CCA is restricted for use in many countries. The UK Environmental Protection (Controls of Dangerous Substances) Regulations 2003 implement the provisions in the EU Directive 2003/2/EC, which introduced a partial ban on the use of CCA (copper/ chrome/ arsenic) as a timber treatment, as CCA is considered to be a carcinogen. The risks from CCA are considered to be very small but a very precautionary approach has been taken in this case (UK Department for Environment, Food and Rural Affairs, 2008) and in the UK waste timber containing CCA is classed as hazardous waste (Department for Environment, Food and Rural Affairs, 2012). As such this is not generally found in retail products.

Other timber treatments that are generally regarded as "rabbit safe" include chemicals such as tributylin (a neurotoxin), and volatile organic compounds such as ammonium hydroxide (sixteen times more lethal for rabbits than copper carbonate (US National Library of Medicine, n.d.))

Ventilation

The natural biochemical processes of rabbits, like any other mammal, produce bodily waste that, if left in the enclosure for protracted periods of time, can cause negative health issues. The most harmful of these is ammonia, which is expelled from the body in the urine and is produced as a result of the metabolism of protein. Ammonia is a toxic molecule, and will produce symptoms ranging from nasal discharge to respiratory disease, which can cause secondary bacterial infection (van Praag, n.d.).

Respiration results in the production of carbon dioxide from the body. While the immediate effects of excess carbon dioxide are well known (e.g. Hypercapnia) elevated concentrations of this gas over protracted periods of time can result in semi-permanent damage to the respiratory system (Wright, 1934).

Sufficient ventilation must be provided so as to not permit the concentration of ammonia to reach levels at or above 20 ppm, and carbon dioxide levels must remain below 0.3% (St, 2008)

Entrapment prevention

While there are no studies showing the likelihood of serious injury or death from entrapment within a rabbit enclosure, there have been several unfortunate documented cases of rabbits becoming trapped and suffocating within their enclosures.

Particular care must be taken in the design, manufacture and setup of a rabbit enclosure so as to prevent entrapment.

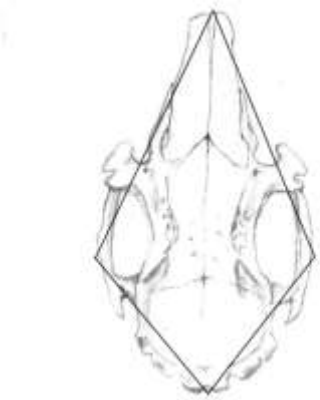


Figure 26: A rabbits skull seen in plan view resembles the shape of an arrowhead, and will become easily stuck in openings where it is able to squeeze through but not retract from.

Figure 27: Fatal entrapment (photo credit: C.L. Stevenson)

As can be seen in the above image, this unfortunate rabbit became stuck by its head between the bars of a mesh run that had an aperture too large and a gauge too thin.

Even smaller aperture mesh can result in fatal entrapment.

Figure 28: The partition wall above this removable floor poses an entrapment risk

Hygiene

While the regular maintenance of hygiene of a rabbit enclosure isn't covered by the Animal Welfare Act, it is however an important aspect of keeping a domestic rabbit. Given the high mortality rates for hygiene related illnesses (17% digestive upset, 10% parasitical/bacterial infection, 8% unknown short term illness, 7% respiratory infection, 2% flystrike), permitting and not obstructing ease of cleaning is an important aspect of enclosure design and construction. Despite being relatively clean animals, rabbits are territorial and in addition to chin gland secretions will inevitably leave detritus wherever they feel they need to, whether it be in their sleeping area, around the perimeter of the exercise area or hidden away in a tiny corner (Buseth & Saunders, 2015), and having access to these areas is crucial. The earlier section on ammonia poisoning highlighted the need for adequate ventilation, which is an important part of hygiene, however it only works if the source of the ammonia is regularly removed. Unremoved detritus can also be a cause of flystrike, as it will attract blowfly to the rabbit's enclosure (UK Vets Online, n.d.).

Figure 29 Flystrke is a potentially fatal condition brought about by poor hygiene (photo credit: Neil Forbes BVetMed)

All materials that are to come into contact with rabbit waste should not absorb waste material so that it cannot be realistically removed by rabbit-safe cleaning materials. There should also be no small panel gaps or areas of the structure where waste can accumulate and not be accessed (e.g. in a corner of a lap joint, a hidden corner). All areas of the enclosure should also be accessible either via an opening door, removable panels, or with the use of a long-handled brush.

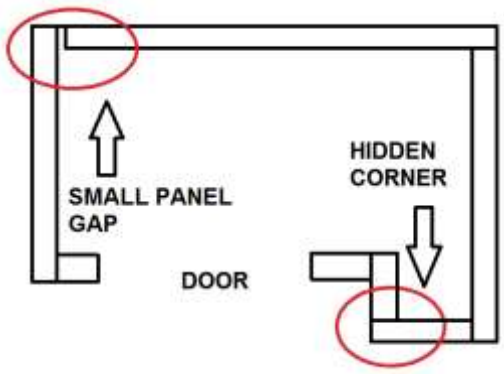


Figure 30: Areas where detritus can accumulate

An enclosure grading system to assess level of compliance with this specification

Given the aforementioned housing requirements as they relate to the basic needs of rabbits according to the Animal Welfare Act 2006, it is advised that enclosure designs are graded in their relative adherence to those needs. The ratings will be classed as follows:

FAIL – does not meet the minimum welfare requirements
C- meets the minimum welfare requirements
B- exceeds the minimum welfare requirements
A- far exceeds the minimum welfare requirements

If an enclosure fails on any of the ratings, by definition it should not be used for housing rabbits, as it does not meet the minimum welfare standards.
For each of the requirements, the grading scheme shall apply in the following manner

Overall Dimensions

- **Footprint**

A - has a footprint greater than or equal to 5m^2 per rabbit, and a minimum length of 1.8m

B – has a footprint greater than or equal to 3.35m^2 per rabbit, and a minimum length of 1.8m

C – has a footprint greater than or equal to 1.68m^2 per rabbit, and a minimum length of 1.8m

FAIL – has a footprint less than 1.68m^2 per rabbit and/or a length less than 1.8m

- **Height**

A – has a hutch height above 75cm and a run height above 120cm
B – has a hutch height above 75cm and a run height above 75cm
C – has a hutch height above of 60cm and a run height above 75cm
FAIL – has a hutch height below 60cm and/or a run height below 75cm

Build Quality

- **Thermal Insulation**

A – The insulation and rabbit body heat increases the temperature of the resting area by 10^{0}C above ambient in colder temperatures, and consideration is demonstrably taken for the mitigation of harmful temperature increases during normal summer weather.
B – The insulation and rabbit body heat increases the temperature of the resting area by 8^{0}C above ambient in colder temperatures, and consideration is demonstrably taken for the mitigation of harmful temperature increases during normal summer weather.
C – The insulation and rabbit body heat increases the temperature of the resting area by 6^{0}C ambient in colder temperatures, and consideration is demonstrably taken for the mitigation of harmful temperature increases during normal summer weather.
FAIL – The housing has no insulation compliant with grades A, B or C

- **Noise Insulation**

A- the resting area can reduce noise levels from frequencies associated with injury and illness to below 75dB
B- the resting area can reduce noise levels from frequencies associated with injury and illness to below 80dB
C- the resting area can reduce noise levels from frequencies associated with injury and illness to below 85dB
FAIL - the resting area cannot reduce noise levels from frequencies associated with injury and illness to below 85dB
Note: not all enclosures will be sited in busy urban areas or subject to elevated noise. As such, a "fail" in this category would mean that the enclosure is "unsuitable for use in noisy areas"

- **Fox proofing**

A – all parts of the enclosure (including roof) can withstand a 30-minute sustained fox attack
B – all parts of the enclosure (including roof) can withstand 15 minutes of fox attack
C – all parts of the enclosure (including roof) can withstand 5 minutes of fox attack
FAIL – at least one part of the enclosure (including roof) cannot withstand a fox attack of up to 5 minutes

Materials

- **Chew resistance**

A – Construction materials are not able to be chewed (e.g. metal framework)
B – Construction materials are not easily chewed (e.g. dense timber)
C – Construction materials can be easily chewed but are protected by trims
FAIL – Construction materials are easily chewed (e.g. plastic)

- **Chemical safety**

A – Enclosure contains zero chemicals that could be hazardous to a rabbit's health, and does not require additional chemicals (i.e. treatment) in order to function
B – the enclosure comprises some components containing potentially harmful chemicals but are not accessible by the rabbits and do not give off any fumes
C – the enclosure contains components with potentially harmful chemicals but not in sufficient quantities to cause detectable health issues
FAIL – the enclosure contains components with potentially harmful chemicals that are accessible by the rabbits

Key Design Features

Enrichment (Presence of steps and hiding places)

A – Enclosure has one or more steps per rabbit, and one or more hiding places per rabbit.
B – Enclosure has one step in total and one or more hiding places per rabbit
C – Enclosure has two levels and two hiding places
FAIL – Enclosure is on one level and/or has less than two hiding places

Ventilation

A – Enclosure has sufficient ventilation such that no enclosed spaces are capable of elevated levels of ammonia or carbon dioxide above normal atmospheric conditions.

B – Enclosure has sufficient ventilation such that no enclosed spaces are capable of elevated levels of ammonia or carbon dioxide that are sufficient to cause adverse health effects.

C – Enclosure has some ventilation for the purpose of allowing excess ammonia and carbon dioxide to escape.

FAIL – Enclosure has no effectual ventilation.

Hygiene

A – The enclosure has no horizontal surfaces that can absorb excreta, no hidden corners or panel gaps, and all areas are easily accessible by a standing person

B –The enclosure has no hidden corners or panel gaps, and all areas are easily accessible by a standing person

C – The enclosure has no hidden corners, panel gaps and all areas are accessible by a person

FAIL – The enclosure has hidden corners and/or panel gaps, at least one inaccessible area, and has horizontal surfaces that easily absorb excreta.

Pass/Fail Check list:

- Partially sheltered exercise area
- 24 Hour Unrestricted access to exercise area
- No "top-down" access
- No entrapment risks

Presentation of ratings on enclosure products:

Putting information on the level of compliance with this specification needs to be as simple as possible for consumers. Several rating systems exist of similar format for other commercial products, public services and manufacturing quality. These take the form of a tiered alphabetical rating from A onwards, with A being the best performance. Some other pertinent information is also shown to elaborate on the reasoning behind the specific rating.

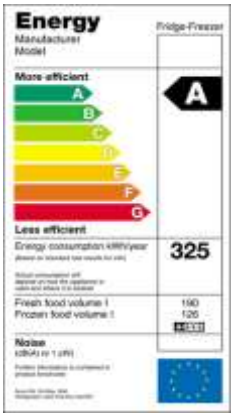
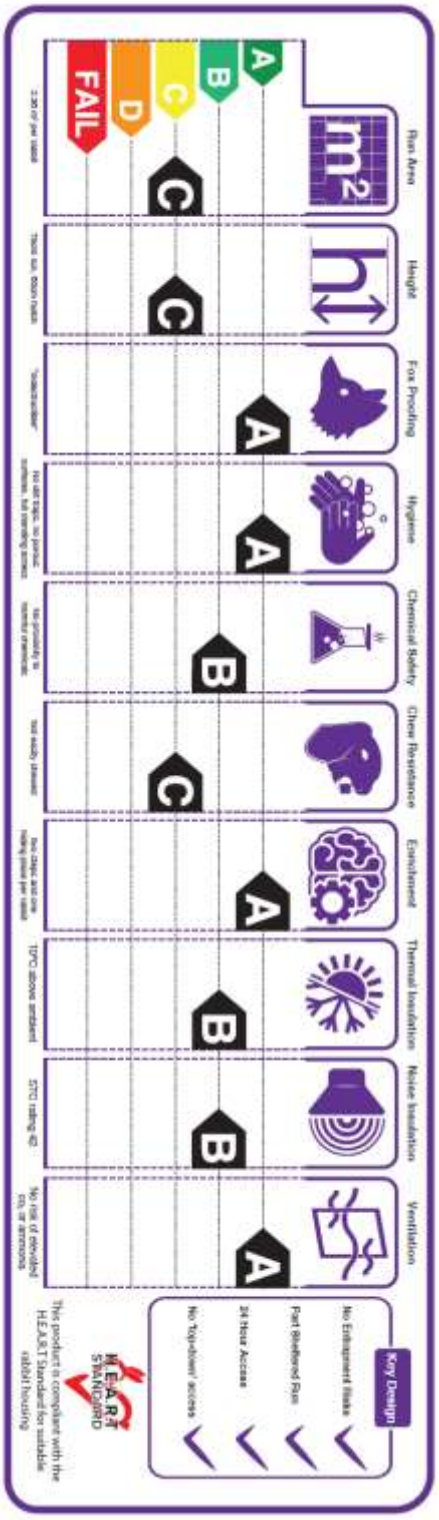
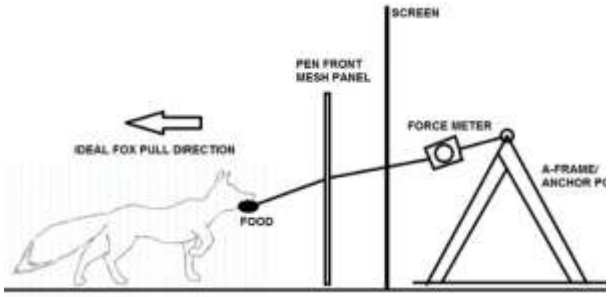


Figure 31: Example of a product rating system

It is recommended that the rating system graphic charts for rabbit enclosures be structured as they relate to the various main headings; "Overall dimensions", "build quality", "materials", and "key design features". The diagrams for specification compliance will therefore be represented as follows:



Appendix 1: Experimental Data of Fox pulling force



Method:

1) Setup screen and a-frame as near as practical to the edge of the pen. Select the appropriate cable length, adjust if necessary.
2) Set up cameras.
3) Pass one end of the cable through the pen and into the hide at a level height, attach to the force meter, finally attach bait.
4) Promptly retreat behind the screen.
5) Observe
6) Record fox behaviour, eating, pulling etc., and readout on force meter.

Test fox mass: 4kg
Maximum fox mass: 14kg
Maximum recorded pull force: 2kg
Scaling factor: 2.3*
Max force: 70N

*Scale factor is derived from the square-cube law as applied to biomechanics and is used to estimate the force from an 8kg fox (Wikipedia, n.d.)

Figure 32: A "hide" setup for the fox pull experiment

Figure 33: A hospitalised young fox using our camera as cover to pull on the bait line

Alternative sources of data:

Design of poison traps:

A study conducted by the Victorian Institute of Animal Science in Franskton, Australia (Petel, et al., 2004) into the design and efficacy of poison ejector assessed the results of traps set at varying activation strengths. As a result of the study, it was found that foxes as small as 3kg body weight were able to activate traps set up to 2.7kg of pull force. Using the scaling rules for animal body weight vs size, this pull strength can be extrapolated by a factor of 2.8 up to approximately 74N. This corroborates the finding from the experiments on foxes in medical captivity.

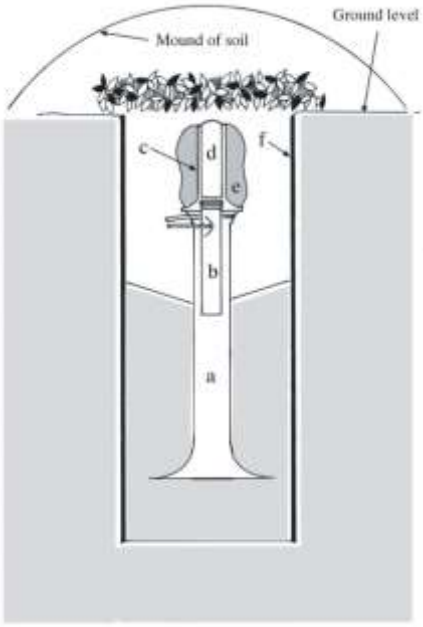


Figure 34: A basic sprung poison ejector design

Limitations

It should be noted that both the experiments on foxes in captivity and the ejector design figures did not take into account the effect of increased autonomic nervous system responses that occur during predatory attacks (Loewy & Michael, 1990), more commonly known as the "flight or fight" response. This response has the effect of increased blood flow, blood pressure, blood sugar level, breathing, hearing, perspiration, and more critically increased muscle tension and strength (Olpin, n.d.). Little is known about the specific percentage increases in strength arising from higher adrenaline concentrations in the blood, however small increases in human muscle tension have been demonstrated (Marsden & Meadows, 1970) therefore it is expected that a similar effect exists in foxes. Therefore, the figure of 74N should be considered a minimum amount of force that a large fox can exert on a rabbit enclosure.

Applying the square-cube law to data taken from a medium sized dog.

As a way of verifying the assertions on suitable pull force, the experimental method of measuring pull strength was carried out on a medium sized, 20kg border collie. Two cameras were used, one a long shot and the other a close up of the force scales, to make sure that the forces measured were for "static" pulls and not from momentum gained from moving away from the a-frame.

Figure 35: Experimental setup and data taken from "static" pulling

The results of this experiment showed an ability for the dog to pull on the scales with a maximum force of approximately 340N, much higher than expected. Using the square-cube law, and scaling this value down for a representative average European red fox weight of 8kg, we get 185N of pull force. Given that this test was carried out in a controlled environment, with less mitigating factors, this value will be used for simulated fox attack testing.

Figure 36: Freeze frame of the highest value pull force showing approximately 35kg (340N) of pull

Appendix 2: Simulating a fox jaw pull attack on a rabbit enclosure

As mentioned earlier, experimental data shows that the average European red fox can pull on enclosures with a nominal force of approximately 185N (18.9 kg).

An appropriate apparatus should be set up to simulate this pulling attack, so that all relevant areas of the structure are pulled on at this force level repeatedly. A suggested method is to use a pneumatic linear actuator, with a known travel, linked to the structure with a spring that has a known force at a known extension.

Using the appropriate facsimile of the fox skull and jaw, set to the proper bite force, each exposed area of the housing should be tested in the following manner:

Areas to be tested:

- Mesh along all sides
- Exposed corners
- Edges of doors
- Panel edges
- Connecting tubes

Ideally housing should be tested to destruction, however should the area to be tested demonstrate "indestructability", as in it has not noticeably weakened or begun to yield after a period of 30 minutes, and it would be reasonable to assume that an unending attack would not further compromise the integrity, then testing may cease and the area in question can be considered indestructible.

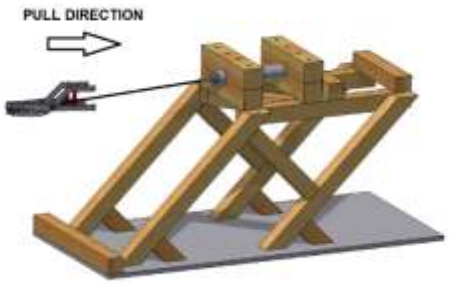


Figure 37: A design of a basic fox pull and gnaw test setup

Figure 38: The "robo fox" setup used in this report

Figure 39: The results of jaw pull testing on chicken wire, real fox skull for comparison

Appendix 3: Simulating a fox jaw gnawing attack on a rabbit enclosure

A reasonable facsimile of a fox jaw should be used. This facsimile should have the following features:

- Similar size and geometry to an average European red fox
- Similar dental layout, and tooth profile
- Similar bite force on the anterior incisor and posterior molar teeth (145N and 240N respectively).
- Similar angle of opening.

Figure 40: Framework and mesh apertures of 25mm and larger will allow a fox's jaw to apply full force while attacking

Figure 41: Any gaps larger than 80mm will allow a fox full access to the interior of an enclosure.

Figure 42: Foxes can open their jaws as much as 90 degrees (photo credit: Peter G Trimming)

To test chew/gnaw resistance, the facsimile jaw should be applied, released, and re-applied ad-infinitum.

Using the facsimile jaw, set to the correct bite force, the following areas of the enclosure should be tested for chew resistance:

- Mesh
- Timber
- Exposed surfaces
- Connecting tubes

Ideally housing should be tested to destruction, however should the area to be tested demonstrate "indestructability", as in it would be reasonable to assume that an unending attack would not compromise the integrity, then testing may cease and the area in question can be considered indestructible.

Figure 43: Gnaw test on mesh using a fox jaw facsimile

Appendix 4: Simulating a fox jump attack on a rabbit enclosure

As discussed in section 4 with regards to the need to protect the rabbits from a fox jumping attack on their enclosure, a simple apparatus is required to demonstrate that the materials and structure of the enclosure is capable of withstanding a repeated assault. To this end, the apparatus should be capable of exerting a representative force on the enclosure that simulates a fox jumping up to a height of 60 cm (approximately 2 feet), and then landing on its two front paws. An example of such an apparatus is shown below.

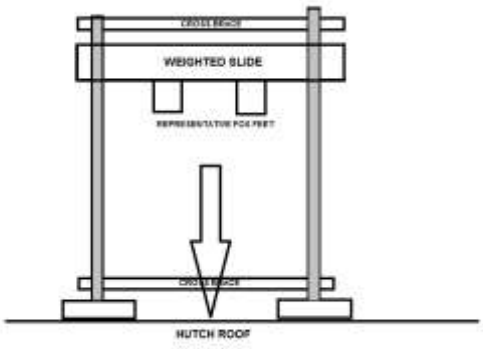


Figure 44: A possible drop test rig configuration

The mechanics of the impact test should have the following mechanical properties:

Weight of slide	8kg
Height of drop	600mm
Speed on impact	11m/s
Kinetic energy at impact	490 J
Force of impact (assume 10g deceleration)	7.6 kN
Pressure of impact (assume 35mm wide paw)	8 MPa (1160 PSI)

Figure 45: An example of a drop test rig

Appendix 5: Thermal certification on a rabbit enclosure

Input values:

- Sleeping area dimensions:
  - Height (m)
  - Length (m)
  - Width (m)
  - Thickness of wall material(s) (m)
  - Thickness of roof materials(s) (m)
  - Thickness of floor materials(s) (m)
  - Size and location of opening(s) (m)
  - Total skin area (m^2)
- Material properties
  - Thermal conductivity (W/mK)
  - Surface resistance (m^2K/W)
- Heating
  - Rabbit(s) body heat at rest (W)
  - Supplementary heating (W)
  - Air changes per hour (n)

Output values:

- Heat required to maintain 7^0C minimum sleeping area temperature
- Total U value of sleeping area (W/m^2K)
- Demonstration that either rabbit body heat or supplementary heating can maintain 7^0C inside surface temperature minimum

Appendix 6: Entrapment prevention inside a rabbit enclosure

The size of an average rabbit skull has been measured to create a simulated skull entrapment tool (see figure 51)

Entrapment prevention (gap size, 25mm to 50mm can cause injury), flexible barriers such as large aperture mesh can be bent to this size.

Any gap within or on the perimeter of the enclosure wider than 35mm but less than 85mm presents a strangulation hazard.

Any gap wider than 25mm on the perimeter of the enclosure presents will permit an average rabbit's forefeet to pass through and then allow a predator to dismember the rabbit.

Figure 46: "hindfoot prints can be 50-95 mm long and 25 mm wide, while forefoot prints are about 40 mm long by 25 mm wide."

Further to designed dimensions, an approximation of a rabbit skull should be used to test any areas under consideration. The specified dimensions for this representative skull model are as follows:

- Length (front to back): 83mm
- Height (top to bottom): 53mm
- Width (side to side): 40mm
- Divergent angle (from tip of nose to extremity of cheekbone): 40 degrees
- Convergent angle (from extremity of cheekbone to rear of skull): 70 degrees

Figure 47: Isometric measurements of an average rabbit skull

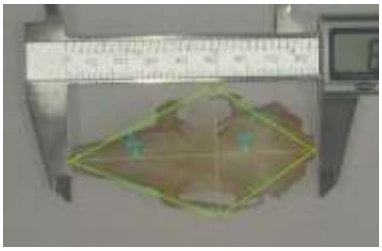


Figure 48: Basic diverging and converging angles of a rabbit skull

Figure 49 The rabbit skull entrapment tool

Appendix 7: Measuring sound reduction on a rabbit enclosure

As mentioned earlier, the most common source of loud noises that are responsible for rabbit deaths are fireworks and dog barking (Cottontails Rescue, n.d.). The highest energy frequencies from fireworks occur in the 125, 250 and 500Hz bands (Tingay, 2011), and the loudest dog barks are in the 700 to 700Hz range (Averbuch, et al., n.d.). LAFmax decibel levels from fireworks typically are in the 100 to 110 decibel range, at spectator distance, with large dog barks around the 100 decibel area.

Given that decibel levels above 80-85 dB are known to cause negative behaviour and health effects, including sudden death, a sound transmission loss of 15-20 for the frequencies associated with fireworks and dog barks should be considered essential. For road noise, studies have shown that levels up to 80dB at a distance of 15 metres from a highway are common (Corbisier, n.d.), therefore a safe noise reduction of 5dB shall be considered essential.

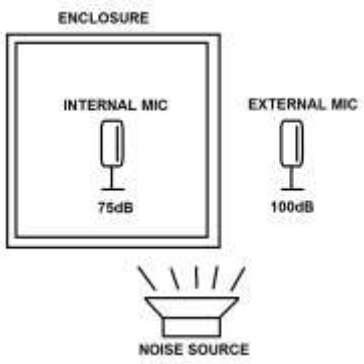


Figure 50: A basic sound insulation test for transmission loss

Figure 51 a large amplifier capable of the frequencies and amplitudes to be measured

Figure 52 the amplifier set to 100dBA at the first frequency of 125Hz

Figure 53: a smartphone is capable of being used as a tone generator for testing specific frequencies

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Disclaimer

No animals were harmed in the creation of this report.

Animal skulls were sourced humanely from wild animals in accordance with the Wildlife and Country Act 1981 and prepared by a certified taxidermist.