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Hypoxic air venting – fire protection for library collections

Christian Nørgaard Madsen and **Geir Jensen**
COWI AS, Norway

Jan Holmberg
Department of Building Sciences
Royal Institute of Technology, Sweden

Abstract

A novel technique to protect library collections and public library spaces from fire – inert air venting - has been evaluated. It prevents fires from starting, allow continuous occupation of protected spaces, cause no secondary damage and offer high reliability. The present paper describes planned applications for an existing medieval building in Italy and for new large public libraries. Fire protection of libraries has always been debated, either for protection systems being a risk by themselves to collections or for not being reliable. A review of conventional and recent options for protecting libraries is made, and the concept of inert air venting is introduced.

Inert air is also referred to as hypoxic air (reduced oxygen concentration) and comprises slightly altered concentrations of components of air. Typically 5 % oxygen is substituted by 5 % nitrogen. Inert air has predetermined oxygen level and safely vents spaces to be protected continuously. Inert air is safe to breathe, but prevent ignition and fire in common materials. Inert air replaces the use of inert gases. Inert air is produced by simple and reliable generators that fit into existing or new air conditioning systems so that no pipes, nozzles or other equipment need to be installed in the rooms to be protected.

The exploration of inert air for fire protection is recent and several milestones have been passed in quick order over the last 10 years. Three years ago the concept of premixed hypoxic air feed into the protected room superseded the technique of nitrogen feed into the room to establish hypoxic air, and made the inert air option more safe, more simple and less expensive. A rush of research and development for various applications are being made, and the potential benefits to libraries are many. Implementation issues on fire safety, health, cost, reliability, maintenance and impact on artefacts and fabrics have been evaluated. A list of hypotheses which state potential benefits and disadvantages for library applications is analysed. The results are promising and the challenges are found to be few and manageable.

Introduction

Fire protection of library collections is a challenge as they typically involve irreplaceable documents, high values per square meter, large open spaces and objects that are tender and easily damaged if subjected to smoke, heat or extinguishing agents in case of fire.

To avoid damage by wetting from fire brigade intervention or from automatic water-based extinguishing systems like sprinklers, water mist and foams, many have looked at various means of gas extinguishing. Automatic gas extinguishing, however, has not proved ideal because it require evacuation and air-tight enclosures. Gas systems are prone to failure because they involve multiple sub-systems to detect, activate and operate. They quickly run empty and may depend on external power supply. Gas systems also do not cool the fire source, so that reignition frequently occur from doors being opened, from gas leakage of the enclosure or due to layering of the gas towards ceiling or towards floor level. Gas systems prevent staff from entering to remove or protect collections until fire brigade arrive. Although inert gases or inert gas blends like nitrogen, argon, Argonite, Inergen and CO_2 do not pose any risk of decomposition products that are toxic, corrosive or harmful to the environment - as do halocarbon based gases like halon or later FE-36, Halotron and others - all other gas concept disadvantages listed above apply.

During the 1990-ies aerosol extinguishing was developed. This technique, which is very simple and inexpensive, expel “extinguishing smoke” on demand that efficiently extinguish fires and leave light and harmless dust only on book shelves that may be brushed away or removed by vacuum cleaner. However, the reduced visibility makes it definitely not to be recommended for staff or public areas or in evacuation routes. A smoke scrubbing technique based on water mist and nitrogen were considered, but is less useful in large volumes, is complicated and several of the disadvantages listed for gas systems apply to smoke scrubbing as well. A few years ago the 3M Company invented “unwet water” - an extinguishing media which is fluid in storage and pipes, but evaporates at 49.2 ºC and behaves like a gas in fire. It has good environmental and toxic properties, but it does not offer the cooling properties of water on solids and requires the same precautions as other gas systems to keep the spaces gastight etc.

One disadvantage of all conventional active fire protection systems for libraries is that they do not prevent damage by the initial fire prior to extinguishment. Another disadvantage of conventional systems is that they all to some extent involve secondary damage to the protected objects.

Full-time inerting by nitrogen or other inert gases have been an option for decades, and offer the added effect of preventing any fire in the first place. It has not been much explored, though, since it only apply to unmanned library spaces and pose a threat to people entering without breathing apparatuses. Systems require considerable amounts of nitrogen to compensate losses, and this would - prior to the introduction of membrane separators for on-site production - involve bulky reservoirs and refilling.

New Concept

Inert air is also referred to as hypoxic air (reduced oxygen concentration) and comprises slightly altered concentrations of components of air. Typically 5 % oxygen is substituted by 5 % nitrogen. Inert air has predetermined oxygen level and safely vents spaces to be protected continuously. Inert air is safe to breathe, but prevent ignition and fire in common materials. Inert air replaces the use of inert gases. Inert air is produced by simple and reliable generators that fit into existing or new air conditioning systems so that no pipes, nozzles or other equipment need to be installed in the rooms to be protected.

As a continuous inerting system it creates an atmosphere that is safe for humans to breath, but in which common materials can not ignite or burn.

- Preventive mode: 15-16 % O_2 (staff occupy area occasionally or normally)
- Suppression mode: 10-12 % O_2 (short term occupation)

The concept of hypoxic air venting in this context is very simple, yet discovered recently: During research on hypoxic air systems it was discovered that the processes of ignition and combustion in a normobaric, hypoxic environment are far different from the ignition and combustion process that occur in a hypobaric natural altitude environment with the same partial pressure of oxygen

This surprising observation lead to an obvious question (Kotliar): "Why do two environments which contain identical partial pressures of oxygen (ie the same number of oxygen molecules per specific volume) affect the processes of ignition and combustion so differently?"

The answer: "The difference in oxygen concentration in these two environments diminishes the availability of oxygen to support combustion. This happens due to the increased number of nitrogen

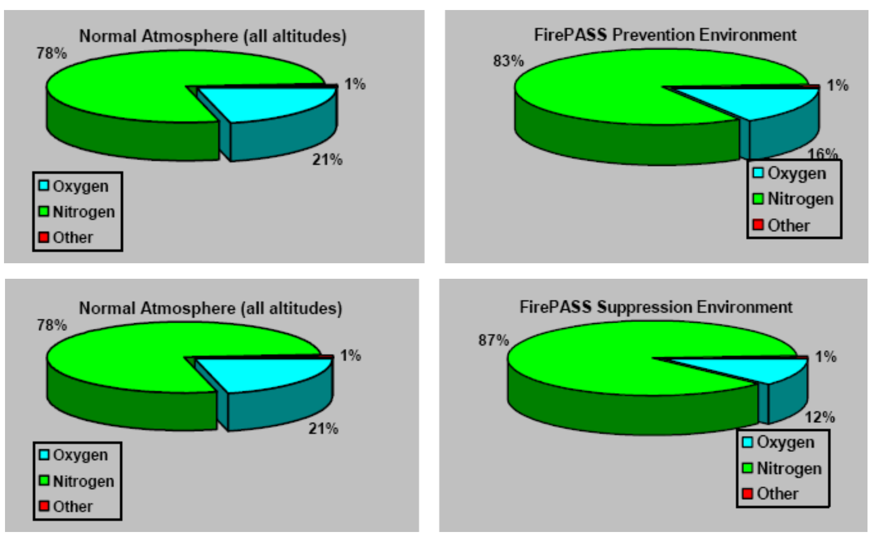

Figure 1: Air (left) and inert air (hypoxic air) (right) /Kotliar/. The oxygen level of inert air for fire prevention is typically 12 to 18 % /FirePASS/

molecules interfering with the kinetic properties of oxygen molecules". In other words, the increased density of nitrogen molecules in the normobaric environment creates a "buffer zone" that obstructs the availability of oxygen molecules for combustion. When the kinetic properties of both gases are compared it is revealed that nitrogen molecules are both slower and have a lower penetration rate (by a factor of 2.5) than oxygen molecules.

Common flammable solid materials and liquids cannot be ignited in environments with oxygen content lower than 16% at normal (sea level) barometric pressure. However, humans can easily tolerate an oxygen-reduced atmosphere with 12 - 16% O_2 (instead of ambient 20.94% O_2) without health hazard (click here for references). In order to better illustrate the differences between the functions of the two oxygen dependent systems, the flame and the human body, we can look to the schematic diagram, the "oxygen – hemoglobin saturation curve and flame extinction curve in normobaric hypoxic environment (Kotliar)".

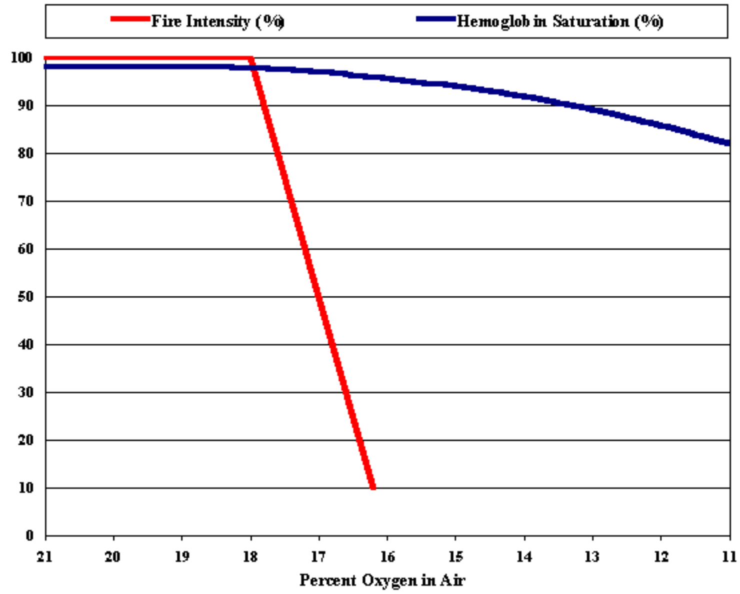

Figure 2 /1/: The red curve represents the decline in combustion intensity. This corresponds to the height of the stable flame and is dependent upon oxygen content in experimental environment. 100 % corresponds to the maximum flame height at ambient atmospheric oxygen content of 20.94%. Below 18% of O_2 we see the continuing linear decline in height of the flame, which at 16.2% results in complete flame extinction.

The blue curve shows the dependence of the oxy-hemoglobin saturation upon the partial pressure of oxygen in inspired air. Because the curve rises quickly with increase of oxygen percent, hemoglobin will be more than 90% saturated if exposed to alveolar pO_2 above 60 mmHg (corresponds to altitude 3300 m. and 14% O_2 in the normobaric hypoxic air). It should be noted that only the partial pressure of the oxygen determines hemoglobin saturation in the capillaries of alveoli. All subsequent oxygen transportation and metabolism depends exclusively upon the balance between oxygen demand and availability via the cardio-vascular system. The partial pressure of neutral diluting gases has no influence on these physiological processes at sea level conditions. In contrast, availability and reactivity of oxygen in the combustion process depends significantly upon the molecular concentrations of other, even inert, diluting gases. The affinity of O_2 to hemoglobin depends only on its partial pressure, while the kinetic of combustion depends on the proportion of oxygen in the gas mixture.

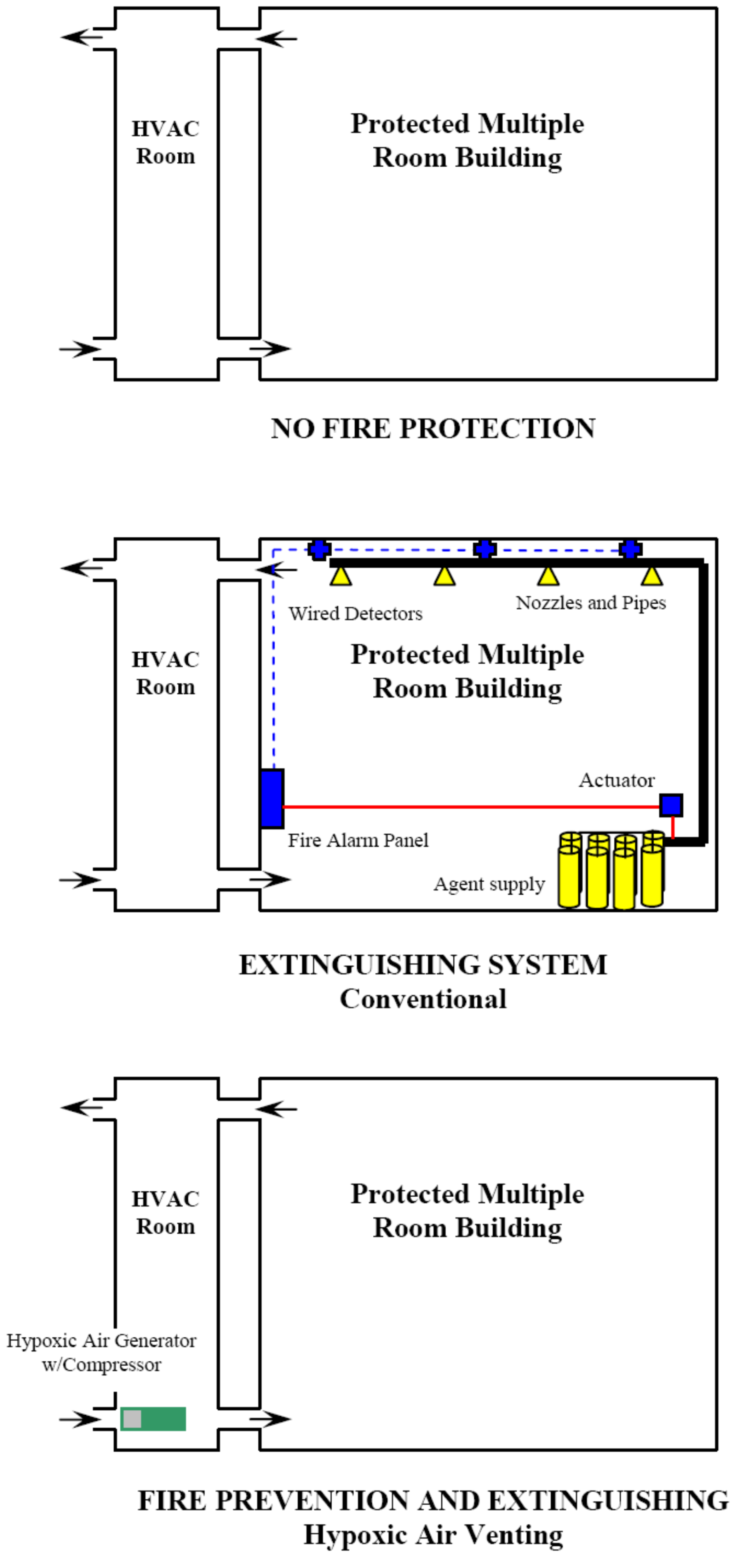

Figure 3:
The simplicity provided by inert (hypoxic) air systems with (bottom) is illustrated by conceptually comparing conventional gas or water based extinguishing systems (middle). Architectural or aesthetical invasive installations are avoided with the inert air concept, which prevent rather than extinguish fires /1/.

Health and Safety

Our literature survey show fairly consistent recommendations for occupation at lowered oxygen levels. There is a gap between allowed limits for aircrafts and general (more strict) limits for enclosures at sea level which does not appear rational. If access to exhibitions is controlled in safe manner, such as not allowing persons with predispositions of relevant diseases exactly as for air flights, inert air of 15% O_2 should cause no concern. That means, inert air is acceptable for all application categories of museums, libraries and historical buildings by simple precautions.

Oxygen Concentration	Symptoms
21%	None (normal Oxygen level)
15%	No immediate effects
12%	Fatigue, impaired judgement
10%	Dizziness, shortness of breath
7%	Stupor sets in
5%	Minimum amount that supports life
2-3%	Death within 1 minute

Figure 4: This guide /Wagner, referenced in 1/ is rough but found to be fairly correct for overview

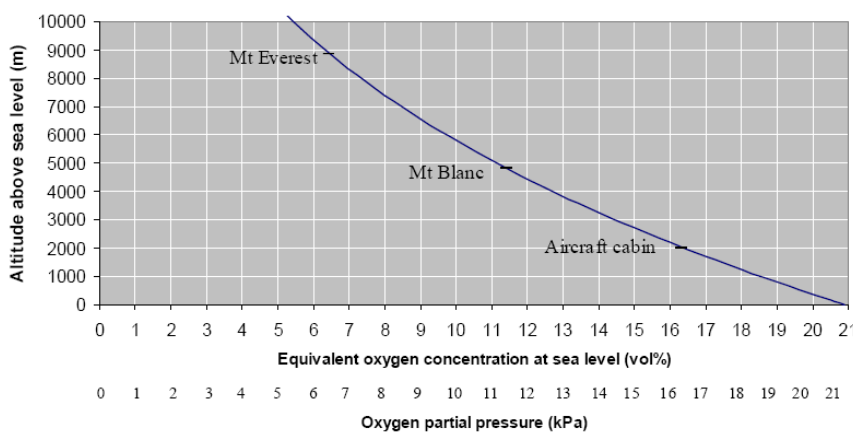

Figure 5: Equivalent oxygen concentrations at sea level versus altitudes /Lund University, referenced in 1/

Health risks - public areas	**Health risks - staff in fire protected premises**
• Exposure to: NO_x, SO_2, CO, CO_2 from: o Fossil fuel burning stoves o Traffic • City centre dust pollution (PM_{10}, $PM_{2,5}$) from traffic • Hypoxic air in aircrafts • Living areas 1500-3000 m above sea level	• CO_2 • Inert gas extinguishing • Fire alarm, no extinguishing system (Staff risk inhaling smoke when fighting small fires, risk back draft from starving fires and may be trapped by unintentional or real CO_2 or inert gas releases)

Table 1: Sample daily life environments posing accepted health risks /1/

As limits of occupation until now are based on systems that control feed of inert gas into rooms, known for uneven distributions, rather than premixed and safe hypoxic air feed, the limits ought to be reviewed as this technology has introduced a substantial safety margin.

There is no documentation that inert air of 13-17 % oxygen poses a risk comparing to or being higher than any of the listed risks in Table 1 if people with predispositions are warned just like prior to entering aircrafts. It is impossible to compare such risks by a single criteria, thus, no documentation exist to prove the opposite either.

Most likely, judging from experience from air flights - containing hypoxic air as used for inerting - hypoxic air venting is less of a risk than any of the other listed risks, when persons predisposed for being affected are warned - similar to boarding air flights. Experience from human population in areas high above sea level is also favourable, but air flights are a worst case to compare with hypoxic air venting because individuals are subjected to sudden changes from normal to hypoxic air, and the occupational times compare to those in rooms in buildings.

To most people regular occupation and controlled exercise in inert air will *increase* their health.

Performances and Benefits of Inert Air Venting

Reference /1/ analysed the various arguments and claims of inert air venting systems as hypotheses. The objectives of that study were protection of heritage, but results apply to all libraries where one is concerned about damage from fire or from secondary damage by extinguishing measures. The conclusions are summarized in table 2.

	STATEMENT OF HYPOTHESIS	CONCLUSION
Pros:		
1	Prevent ignition *(contrary to gas extinguishing systems)*	**Yes** Does retard smouldering combustion as well
2	Prevent smoke release prior to fire extinguishing (contrary to gas extinguishing systems)	**Yes**
3	Prevent backdraught *(contrary to gas extinguishing systems)*	**Yes** Limited holding time of *extinguishing* systems allow for reignition or smouldering: may cause backdraught
4	Fully benign to environment *(contrary to halon and other gas extinguishing systems)*	**Yes**
5	Not toxic, no residue, no added risk of corrosion	**Yes**
6	Allow considerable room air leakage *(contrary to gas extinguishing systems)*	**Yes** Energy costs prohibit large leakage application
7	Allow open doors for rescue of artefacts, manual intervention, evacuation *(contrary to gas extinguishing systems)*	**Yes**
8	Do not run empty *(contrary to gas extinguishing systems)*	**Yes**
9	No refilling, transport or resetting issues following incidents	**Yes**
10	Applicable to small vital rooms and vaults	**Yes**
11	Applicable to very large room volumes *(galleries or multistory, multi-room historic buildings)*	**Yes**

12	Applicable to moderately leaky historic rooms where fixed permanent seals are not acceptable	**Yes** Energy consumption prevents cost-effective applications if very leaky. Imminent next generation membrane separators expected energy-efficient.
13	Applicable to protection of artefacts which are extremely sensitive to smoke, particles, water, corrosive gas or mechanical impact	**Yes**
14	The inherent simplicity promises high reliability.	**Yes**
15	No installation of nozzles, pipes etc in protected room (when inert air generators are integrated in planned or existing utility air conditioning systems)	**Yes**

Cons and Challenges:

A	Health risk for predisposed individuals in *public* spaces	**Yes** Yet, inert air public exhibitions found acceptable when visitors informed.
B	Some fuels in special spaces like laboratories may require suppression mode and evacuation.	**Yes**
C	Secondary effects of continuous high concentration of nitrogen on fungus or other biological processes thriving by nitrogen.	**No**
D	Nitrogen feed systems may cause uneven oxygen levels and complexity to ensure inert air in multi-rooms.	**Yes**
E	Power consumption may cause high energy costs.	**Yes** If room very leaky in the normal state Imminent next generation membrane separators expected energy-efficient.

Table 2: Conclusions from independent evaluation of manufacturer claims and research hypotheses /1/

A qualitative comparison of fire protection options in heritage environments are shown in Figure 1. It is a useful overview for qualitative discussion of parameters, but not for decision making. The figure show a favourable ranking of inert air venting based on the lack of secondary damage risks, and on the simplicity, related to the concept.

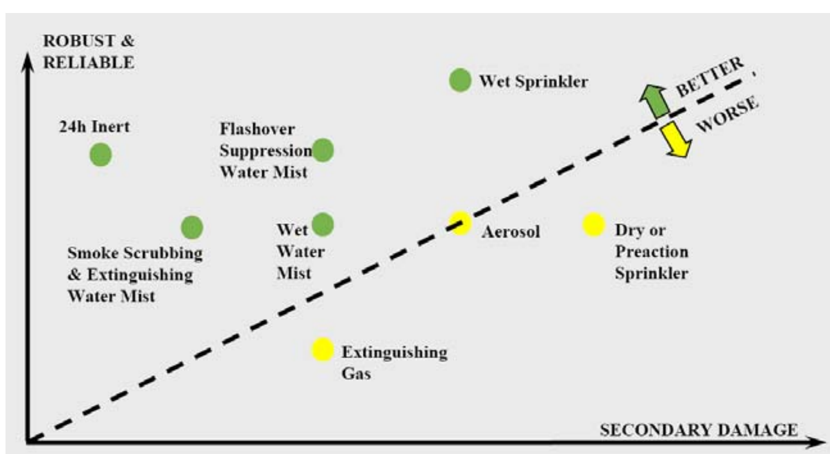

*Figure 6: A qualitative comparison of two vital properties of fire protection systems for heritage. CAUTION: The illustration does not apply to any single object, and relates to two properties only: **risk of secondary damage and robustness/ reliability**. Thus, aesthetics, cost, maintenance, space requirements etc are NOT considered in this evaluation (see elsewhere in this report for evaluation of the latter properties). /1/*

Sample Designs of Inert Air Venting for Fire Protection of Libraries

The Arezzo Public Library – A Heritage Building including Collection Items from the 13th Century

Pretorio Palace is one of the most famous buildings in the historic centre of the city. It is an example of Mediaeval and Renaissance architecture and derives from the union of three buildings built in 1200, belonging to the Guelph families of Albergotti, Lodemari and Sassoli. In 1209 Palce Albergotti became the seat of the Captain of Justice and in 1404 Palace Sassoli, purchased by the city-state, was turned into a prison. In 1632 Palace Albergotti was also purchased by the Municipality and the prison was enlarged. Only in 1926 the prison was moved to another building in Garibaldi Avenue. From that year restoration works started under the supervision of Architect Giuseppe Castellucci. Such works allowed the Mediaeval Museum and the Municipal Gallery to be hosted in the Palace. The palace shows inside the signs of ancient occupancies and arbitrary restoration operations, with a pragmatic use of architectural and sculptural elements as ornaments and furnishings. A coffered ceiling dating back to the 1600s was removed from the city monastery in 1930 and placed into the Library Director's office. On the mezzanine one can admire a gothic stone tabernacle containing a fresco of the Spinelli school and decorated with the typical cornice of arches and lobate endings. All rooms of the Palace witness the different historical periods with frescoes, wooden ceilings and sculptures, which lead visitors' imagination to the past.

Figure 7: Arezzo Public Library

The building holds archives, study rooms as well as conference rooms and general service rooms.

The collection at Arezzo Public Library contains 145.000 items, among which there are books, and documents starting from the 13th century. Moreover, there are windows glasses, frescoes and marble decorations, which are valuable items in terms of susceptibility to become damaged by, smoke, heat, corrosive gases, water, mechanical impact etc. During daytime from 0830-1700 the building is occupied by staff and visitors.

Today the building are natural ventilated only and there is about 0.2 cm openings around windows and doors. About 50 % maximum, of the opening area of door(s) may realistically be open at a fire incident difficult to assess.

The building is constructed by brick works. It holds no voids, shafts etc currently holding or being used as ducts, or such that may be used as air ducts, it is difficult to find available space/room for inerting system equipment (space required similar to other systems) or spaces dedicated to extinguishing systems only.

In addition to general concerns about applying conventional automatic extinguishing systems (water based, gas etc), this building offer these challenges:

- water based: difficult to incorporate pipes, water reservoir
- gas: impossible to reduce building or single room leakages sufficiently to ensure gas holding time

In Table 3 each area is described by occupancy type and time in hours per day. The suggested hypoxic environment oxygen content and technical solution are shown in Table 4.

Area	Occupancy type	Occupancy time in hours per day
Public rooms e.g. conference rooms, exhibition areas and general public area	Public	8
Study rooms	Public	8
Offices	Non-public	8
Technical/service rooms (e.g. toilets)	Non-public	0,5
Storage rooms	Non-public	0,5
Archives	Non-public	1

Table 3 Building areas

Figure 8: Heating plant and part of interior.

For this building, either of three different solutions might be feasible:

- Central hypoxic air unit; hypoxic air distribution by natural ventilation
- Local installations for selected areas
- Local hypoxic air units supported by one central compressor unit

If the natural air flow enables a stable and secure hypoxic air situation at the different areas of the building, supported from a central hypoxic air unit, this will be the most feasible solution, as in this case the installation makes no irreversible changes to the building. However, such a solution has to be studied more in depth based on both air flow measurements and analysis.

Another solution might be to protect selected areas, as the archives, by local installations as shown in Figure 9. This will protect these areas quite well, but the rest of the building is still at risk. By this solution, one also has to take into consideration the air leakage of rooms due to open doors and infiltration.

The last option is to install local hypoxic air units in several areas supported by a central compressor unit. This makes a safe and controlled solution, but requires installation of both a relatively large hypoxic air unit and a piping system to distribute the compressed air.

For this building we estimate that the gross volume of protected areas will be approximately 6000 m^3. 1 air exchange per day makes a power-demand of 25 kW, and 300 kW allow 12 air exchanges per day.

Area	**Acceptable hypoxic air (health)**	**Recommended hypoxic environment**	**Technical solution**
Public rooms e.g. conference rooms, exhibition areas and general public area	15,5-17,4 %	16 %*	Linked to compressor system/ Single, separate hypoxic air system / supported by natural air flow
Study rooms	15,5-17,4 %	16 %*	Linked to compressor system/ Single, separate hypoxic air system / supported by natural air flow
Offices	15,5-17,4 %	16 %*	Linked to compressor system/ Single, separate hypoxic air system / supported by natural air flow
Technical and service rooms (e.g. toilets)	13-15 %	15 %*	Linked to compressor system/ Single, separate hypoxic air system / supported by natural air flow
Storage rooms	13-15 %	15 %*	Linked to compressor system/ Single, separate hypoxic air system / supported by natural air flow
Archives	15,5-17,4 %	16 %*	Linked to compressor system/ Single, separate hypoxic air system / supported by natural air flow

** To be reviewed in detailed design*

Table 4 Recommended Inert (hypoxic) Air Design Values for Arezzo Public Library /1/

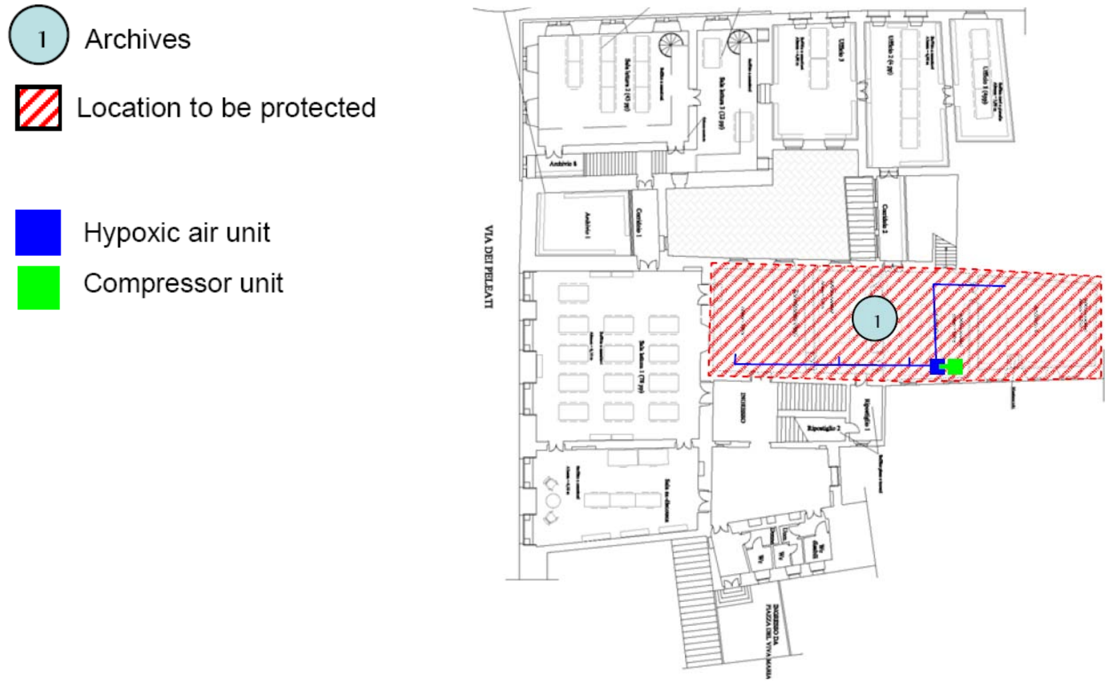

Figure 9: Limited area installation

Modern New Libraries in Oman

Two new libraries - the seven floor 64 000 m^3 New University Building in Oman and the Public Library of Nizwa - are currently planned for complete inert air protection. According to plans they may simply be equipped with hypoxic air generators and compressors within each HVAC plant (one library include 14 plants). More than a thousand visitors may be present at any given time. Standard arrangements to protect from dust, severe weather and building leakage ensure that the fire proof atmosphere is consistent and power consumption at a minimum. Even if emergency power fails at a fire threat, all rooms will be adequately protected for considerable time by the slowly diluting atmosphere.

Conclusion

Inert (hypoxic) air venting is found remarkably promising for application to all library room categories.

Inert air prevent ignition, initial smoke and fire spread. Storage rooms, staff and public spaces may be protected. Public spaces should be treated as airplanes by not allowing individuals with predispositions for disease in hypoxic air, as the inert air atmosphere is equal to that in airplane cabins. Pipes, nozzles or any equipment in the protected rooms are not required. No room fans, no room sensors, no detection and no activation systems are required. The inert air is continuously generated on site, demanding minimum of space. Generators couples to building HVAC and compressors. No reservoirs are required that may run empty or require refilling, such as by conventional hydrocarbon or inert gas extinguishing systems.

There is virtually no risk of secondary damage, environmental or corrosive issues. The inert air will positively contribute to the diminishing of normal deterioration of organic and non organic objects as well as décor.

A challenge of implementing inert air systems is to optimize energy cost, which depends strongly on air exchange rate and air leakage. Compressors must be located or encapsulated to reduce noise. Analysis must be done to ensure that any special substance which may burn at low oxygen level are taken care of by other measures as with any inert gas extinguishing system, or by incorporating an inert air suppression-mode option.

Some national code limits of oxygen level for confined enclosures in buildings may require special permit, or management measures such as control of staff or public areas to prevent access of individuals predisposed for heart disease etc.

Conclusions regarding the hypotheses for the study are summarized in table 2. The inherent simplicity of inert air venting promise unsurpassed reliability compared to most active fire protection systems.

Hypoxic air environment in a building or vault will positively contribute to the diminishing of normal deterioration of organic and non organic objects as well as interior decorations in historic buildings.

If any "health knowledge gap" issue exist on hypoxic air, it is as much about how much health increase, as it is about how much health may be impaired, to occupants.

The main challenge appear to be running costs due to the energy consumption in applications which require high air exchange rate or have great leakage rate. Careful engineering of hypoxic air units and the way they fit to the HVAC may compensate. Both hypoxic air generators and nitrogen generators are relatively new technologies in mass production, and more efficient units are expected. Not least, when location specific analyses are performed to review air exchange rates they may prove general code limit are too strict, and allow energy savings.

Contrary to most other extinguishing media inert air is promising for effective protection during escape from terrorist incidents involving fire or toxic agents in structures. Inert air may also protect libraries in similar large scale incidents, and allow for removal and rescue of valuable items.

The Arezzo Public Library building offer moderate challenges in incorporating the installation and contain irreplaceable cultural values. Therefore, it should gain the most of benefits from inert air systems. Case studies of three heritage buildings concluded that all buildings may be well protected by properly designed continuous inert air (hypoxic air) systems. Full coverage inert air venting is currently planned for two new public libraries in the Middle East.

References

1 Jensen, Gussiås, Melgård, Fjerdingen (COWI AS), Holmberg (Haftcourt Ltd): *Hypoxic Air Venting for Protection of Heritage*. Historic Scotland and Riksantikvaren the Norwegian Directorate for Cultural Heritage. Provided for COST – the European CO-operation in the field of Scientific and Technical Research - Action C17 Built Heritage: Fire Loss to Historic Buildings. June 2005.

Sources listed in the above report are occasionally referred to by name of author/source in this paper.