Passive cooling of existing office buildings – proposal for a building typology

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ABSTRACT: To ensure successful refurbishment of an office building with passive cooling measures, the suitability has to be assessed.
In the paper, both building-related and building-independent factors are discussed, and a typology is proposed. This typology allows buildings to be identified and classified according to their suitability for a passive cooling approach as part of a retrofit. A “decision matrix” finally combines building-related and building-independent parameters, and reveals the building's potential for passive cooling at an early stage of planning.

Keywords: refurbishment, office building, passive cooling techniques, building typology, renovation

1. INTRODUCTION

About one third of the non-residential building stock was constructed less than 30 years ago [1]. Despite this relatively short period of usage, there is already need for renovation to improve comfort and reduce energy consumption, particularly among office buildings. The reasons include:

- short "service life" (adaptation to requirements on working conditions) for office buildings
- higher user expectations (equipment and workplace quality)
- high market standards due to the oversupply of office space
- high annual primary energy consumption of between 200 and 600 kWh/(m²a) [1].

In addition, user comfort is not guaranteed in many buildings due to the indoor conditions during summer. If air-conditioning is installed, the technical and indoor climatic concept can be completely undermined by high operating costs, inadequate maintenance and symptoms of the "Sick Building Syndrome" [2].
Passive cooling uses natural heat sinks (e.g. night air, earth) to remove heat deliberately and make use of storage effects. The limited capacity of most of the heat sinks suitable for passive cooling means that a low cooling load for the building is a pre-condition for applying this technology [3].

There is significant potential for improving the indoor climate in many existing buildings, without installing an air-conditioning system, by introducing passive cooling measures as part of a renovation. However, success depends strongly on the initial conditions offered by the location and the building. Thus, there is a need for a building typology which allows the suitability of a building to be assessed at an early stage of planning.

2. EXISTING TYPOLOGIES FOR OFFICE BUILDINGS

Building typologies are designed to serve different purposes, so that the classification schemes vary accordingly. Conceivable criteria include the historical architectural period of the buildings, their external design, the internal partitioning, the construction type and the type of usage.
Table 1 lists existing typologies for office buildings which were found by research of the literature. The overview shows that there are different typologies for specific purposes, but there is no generic systematisation which would be equally well suited for all questions.

Table 1: Typologies for Office Buildings

Purpose	Sorting Criterion	Ref.
Office usage and organisation	Office type, type of work	[4],[5], [6]
Statistical surveys	Usage	
Standards	Office type	[7],[8]
Office operating costs	Air-conditioning, building age, location	[9]
Energy consumption profile	Ventilation, air-conditioning, office type, usage standard	[10]
Energy consumption scenarios	Building age, building type, usage	[11]
Renovation scenarios	Exposition, storage mass, function building envelope, office type	[12], [13], [14]

The next section therefore presents our own typology, which serves to identify those office buildings in which renovation concepts with passive cooling measures can be applied successfully. This typology is based partly on elements of the typology to prepare renovation scenarios.

3 TYPOLOGY TO ASSESS THE BUILDING POTENTIAL FOR RENOVATION APPLYING PASSIVE COOLING MEASURES

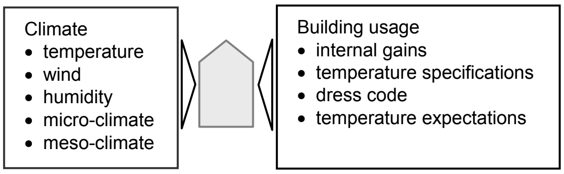

Fig. 1: Building-independent factors.

To prepare a typology applicable to passive cooling, initially the criteria for assessing the potential of a building for passive cooling must be gathered. Two levels can be identified:

- factors independent of the building, which either affect the building (climate), or are related to the building usage (dress code), but are not caused by the building itself or its design (fig. 1)
- building-related parameters (construction type, internal partitioning)

Consideration of the factors which are independent of the building provides information on whether the building usage is fundamentally compatible with a passive cooling concept and whether the climatic conditions (here Germany and Central Europe) are favourable. The building-related parameters determine whether the building construction offers the potential for passive cooling.
Figure 2 illustrates the interaction between the "building-independent" and "building-related" levels.

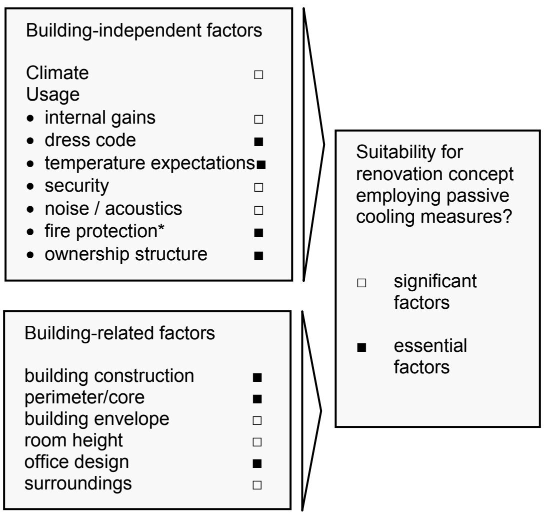

Fig. 2: Decisive factors affecting the suitability of a building for renovation introducing passive cooling measures.
*If – despite the high investment costs – a sprinkler system is installed, certain fire protection requirements can be neglected.

At both levels, there are quantities (marked with a black square) which are regarded as pre-conditions for implementing the concept, and other factors which can be advantageous or disadvantageous to varying degrees.

3.1 Building-independent factors

3.1.1 Climate

The indoor summer temperatures can be lowered by night ventilation at many Central European locations, as the outdoor temperature generally falls to ≤ 18 °C during the summer nights.

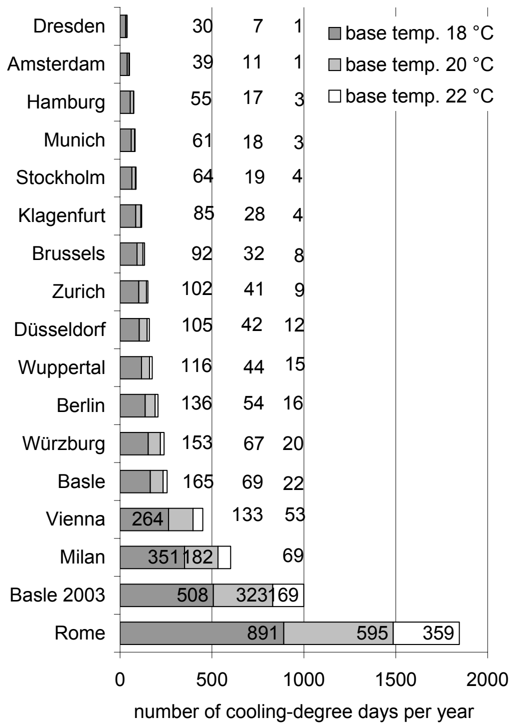

Fig. 3: Annual cooling degree-days. Cooling degree-days are calculated as follows:
CDD = $T_{out\,(24\,h)} - T_{base}$,
where $T_{out\,(24\,h)}$ is the daily mean outdoor temperature and T_{base} is the base temperature. The base temperature is defined for summer as 18°C, 20°C or 22°C. This correlates with the daily mean outdoor temperature limit where the air temperature in the building would exceed 26 °C. Buildings offering very poor control of solar gains would reach this point already at 18 °C, better protection against thermal gains would lead to a base temperature of 20°C or ideally to one of 22°C.
Comment: The room air temperature in summer is dependent not only on the properties of the building envelope but also on the building's thermal inertia, internal gains and user behaviour. Base temperatures used as above can help to classify different climatic conditions. However, cooling degree-days do not allow conclusions to be drawn about the cooling load of the building.
Source: Meteonorm, data for Basle 2003: University of Basle, CH.

3.1.2 Internal gains

According to [15], internal gains can be classified as in Table 2. The lower the internal gains, the smaller is the thermal storage capacity needed or the amount of heat which must be extracted.

Table 2: Internal gains per m^2_{NFA} (net floor area) according to SWKI Guideline 95-3 [15].

	Internal gains for individual and group office (≤ 6 persons) (Wh/[m^2_{NFA}d])	Internal gains for open-plan office (≥ 6 persons) (Wh/[m^2_{NFA}d])
Low	143	142
Medium	191	198
High	264	286

3.1.3 Influence and adaptation by the users

In a building which is not air-conditioned, the users should be able to change and adapt the indoor climate e.g. by opening windows and operating sun-shading devices. According to [16], 85% of surveyed office workers expressed a wish to influence the indoor climate directly. The investigation also showed that if this is possible, the cases of discomfort reported by the users are fewer than in a building without the possibility for direct influence.

The building usage should not require compliance with a strict dress code, as this makes it more difficult for the users to adapt to the indoor climate. The example calculated in Table 3 for different amounts of clothing in the same thermal environment underlines the negative effect of a dress code on thermal comfort.

Table 3: Effects of different clothing on thermal comfort. The example is based on the following assumptions: operative temperature: 26°C, relative air humidity: 50%, air velocity: 0.13 m/s, metabolic rate: 1.2 (seated person).
PMV stands for “predicted mean vote”, PPD for “percentage of dissatisfied”. DIN EN ISO 7730 defines a PPD index ≤ 10 % as acceptable.

Insulating effect of clothing	**PMV**	**PPD**
Clo 0.5 light trousers (short skirt), T-shirt	0.22	5.97
Clo 0.7 trousers (skirt), singlet, long-sleeved shirt (blouse)	0.52	10.72
Clo 1.0 suit	0.85	20.36

3.1.4 Temperature expectations of users

A building without active cooling experiences larger temperature swings in hot periods of summer. Later disappointments can be prevented by informing the users realistically and at an early stage. If an installed air-conditioning system is not used because the energy consumption was too high, and not because the users were dissatisfied, and if the users are the same people before and after renovation, caution is recommended. As the users have been accustomed to cool rooms also in summer, they will react particularly critically to a greater temperature range. One method to investigate user expectations of the indoor climate is to conduct a user survey (E. Gossauer in [17]).

3.1.5 Security

From the perspective of insurance companies, open sections of the building envelope (ventilation flaps, windows) at night presents two insurance risks: damage due to burglary (ground floor) or rainwater penetrating through ventilation openings. The insurance total is always determined with reference to the specific building. It is advantageous to have early negotiations with the insurance company to clarify which solutions are acceptable for which price.
If special requirements are imposed by the need for data protection (office doors must remain closed at night), it is important to know whether clerestory windows to the corridor can remain open (free convection - or not (mechanical ventilation). Note: experience shows that free convection is only effective for night ventilation in the case of specific architectural configurations to increase the stack effect.

3.1.6 Ownership structure

Court judgements of the past (e.g. OLG Hamm 1994, OLG Rostock 2000, OLG Bielefeld 2003) show that the landlord has to rent the building to the tenants in usable condition. Temperatures > 26°C have been seen critically. Operating the building with passive cooling measures against the tenants' will is not conceivable.
An advantageous structure is thus one in which the user and the owner are identical. A further approach would be the classification of summer thermal comfort achievable in contracts, e.g. according to the comfort classes proposed in prEN 15251. If the possibility has been discussed in advance, acceptance of higher indoor temperatures on occasions then does not usually present a problem. Special agreements between the planner and the building owner about higher temperatures help to prevent subsequent legal conflicts.

3.1.7 Noise / Acoustics

High demands on acoustic insulation between offices and corridors can be met, but are more complex technically if combined with passive cooling and cause higher investment costs. In general, for the room dimensions considered here, building practice shows that acoustic comfort within a room is given, even for uncladded ceilings.

3.1.8 Fire protection - planned functional units and dimensions

In larger office buildings, it is favourable to combine functional units to a floor area of less than 400 m^2. Under such conditions circulation areas can be adopted for multipurpose use (placement of fire loads such as copiers is possible). Air flow can be organized simply and inexpensively. However, some State building regulations can include different specifications.

Table 4: Building-independent factors, which are relevant in assessing the building's potential for refurbishment applying passive cooling measures.
FU = functional unit

favourable	neutral	unfavourable
Climate		
< hot periods < summer nights with T_{out} ≤ 18 °C < cooling degree-days (e.g. Dresden)	± hot periods ± summer nights with T_{out} ≤ 18 °C ± cooling degree-days (e.g. Zurich)	> hot periods > summer nights with T_{out} ≥ 18 °C > cooling degree-days (e.g. Rome)
Internal gains [Wh/[m²$_{NFA}$d]		
<150	<200	>200
Clothing		
individual choice of clothing		dress code
Temperature expectation		
Summer: users willing to accept > temperatures		Summer: users not willing to accept > temperatures
Security		
Night: Office doors open within FU, openings in building envelope possible		Night: Office doors closed within FU, building envelope closed
Acoustics		
< transfer of sound between offices and corridors acceptable		high demands on acoustic insulation between offices and corridors
Fire protection		
FU < 400 m² are possible		FU > 400 m² are necessary
Ownership		
Owners and users identical		Owners and users not identical

3.2 Building-related factors

3.2.1 Surrounding buildings

In addition to the geographical location of the building, the immediate surroundings play an important role for the microclimate. An urban location results in temperatures which can often be significantly higher than for a nearby meteorological station (heat island).

The surrounding buildings affect the efficiency of natural night ventilation for a building in two ways: adjacent buildings reduce the number of possible positions for outdoor air to enter the building, and the immediate surroundings change the wind profile (intensity and direction).

3.2.2 Building construction - thermal storage capacity

The storage mass (heat capacity) of a building stabilises the room temperature. Large storage masses serve to smooth out temperature fluctuations over several days. If the classification of construction type according to various standards is compared (table 5), the greatest deviations between [18] and [19] are found for the lower limit of "heavy construction". This can be partly explained by different calculation procedures. The values specified in [18] are adequate for coarse classification for the purposes of the building typology.

Table 5: Definition of the heat storage capacity of a room according to different standards. The numbers refer to the floor area of the room. VL = very light building construction, L = light building construction, M = medium building construction, H = heavy building construction.
A = kg/(K*m²), B = Wh/(K*m²)

	[18]		[20], [21], [22]		[19]	
	(A)	(B)	(A)	(B))	(A)	(B)
VL	-	-	-	-	<150	<50
L	<300	-	-	<50	150 – 300	50 - 100
M	300 – 400	-	-	<130	300 – 800	100 - 200
H	>400	-	-	>130	>800	>200

3.2.3 Room height

If a central supply and exhaust air is to be installed, the clear room height in rooms where ducts may be mounted (corridor and the adjacent zones of offices) should be at least 3.0 m. If a suspended ceiling is then installed 0.5 m below the structural ceiling, the room height would still be 2.5 m.
If an exhaust air system with decentral supply air inlets in the façade is to be used, room heights of up to 2.8 m would be possible, as the suspension depth needs to be only 0.3 m (no duct crossing).

3.2.4 Office position within building (perimeter/core)

If the offices and the workplaces are adjacent to the building envelope, it is generally possible to achieve natural convection and good daylighting at the workplaces. In offices without an outside wall, the increased need for artificial lighting raises the internal gains, such that mechanical ventilation is usually needed.

3.2.5 Window-to-wall ratio

As the heat gains through the opaque walls are low due to the current high standard of thermal insulation, it is the window-to-wall ratio and the combination of glazing type and sun-shading system

(g_{total} value according to prEN 14501), which determines the magnitude of the solar gains.
Window-to-wall ratios between 30 and 40 % (+ sun-shading) offer favourable starting conditions for passive cooling measures to be effective. The room temperatures in the building can be controlled sufficiently, even if the user behaviour is unfavourable. In the other case a highly selective solar control glazing can reduce the external load and improve the robustness of the building thermal concept.

3.2.6 Office design - internal partitioning

Offices for a single person or a few people are advantageous. These can be naturally ventilated and illuminated, and on the other hand, the users can actively influence the indoor climate. Combination offices can also be suitable under certain conditions (e.g. buildings with double-loaded corridors with cross-ventilation and a central core zone, which is not used as a permanent workplace). Open-plan offices with flexible furnishing options are not favourable. This is due to the higher demand for an average, mainly constant indoor climate.

Table 6: Building-related factors which are relevant to assessing the building's potential for refurbishment applying passive cooling measures. (H, M, L = refer to Table 5).

favourable	**neutral**	**unfavourable**
Proximity to surrounding buildings		
free-standing (free convection)	adjacent buildings on two sides (cross-ventilation)	adjacent buildings on two sides, narrow courtyard situation
Storage mass [kg/m²]		
H = > 400	M = 300 – 400	L = < 300
Office position		
offices along building perimeter (free convection, daylighting)	deep and/or "trapped" offices	offices enclosed in building core (mech. ventilation, artificial lighting)
Window-to-wall ratio		
window-to-wall ratio 25 - 35 % (single windows)	window-to-wall ratio 35 - 60 % (window strips)	window-to-wall ratio ≥ 60% (completely glazed façade)
Office design		
small offices	medium-sized or combination offices for ≤6 persons	open-plan offices
Room height [m]		
> 3 (clear)		< 3 (clear)

3.3 Typology

Figure 4 shows the heavy-construction building types which present favourable pre-conditions for renovation to introduce passive cooling measures. Buildings with lightweight construction and those with open-plan offices as the internal partitioning form have been eliminated at a fundamental level. Note: We have decided against presenting the typology for buildings with medium-weight construction here.

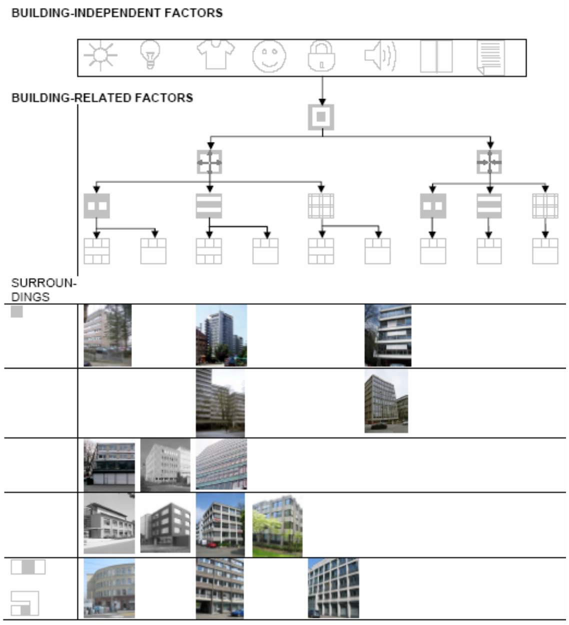

Fig. 4: Heavy-construction buildings with potential for refurbishment applying passive cooling measures.

The decision matrix (fig. 5) to assess the building potential for passive cooling combines the building-independent and the building-related criteria. This provides a tool to decide on the fundamental suitability of a building for a passive cooling concept at a very early planning stage. The next step would then be the preparation of feasible renovation concepts.

4 CONCLUSION

A literature search revealed that a typology to classify office buildings according to their suitability for passive cooling has not been prepared previously. Thus, the paper presents and evaluates the building-related and building-independent properties which are relevant to such a cooling concept. The potential of a building for passive cooling can be assessed with the help of the decision matrix.
However, it should be remembered that the internal usage and partitioning of a building often vary

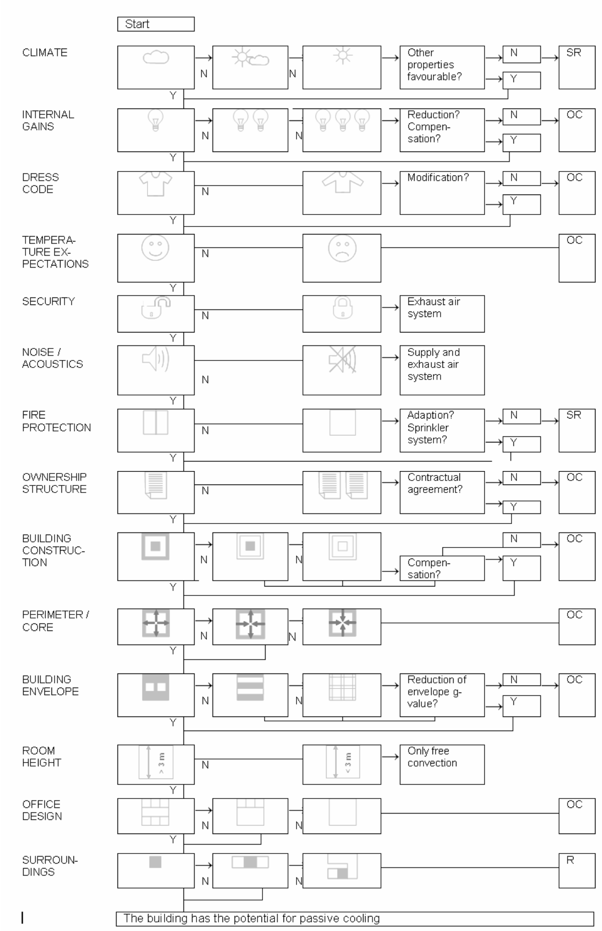

Fig. 5: Decision matrix to assess the potential of a building for passive cooling throughout the building. Also, there may be zones with different construction types within a single building. To prevent incompatible types of building service technology being installed, an overview should be gained during the initial data gathering phase (service phase 1, HOAI) to determine how large the proportion of the building is, for which renovation for passive cooling is at all realistic.

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