INDOOR AIR POLLUTION BY FUNGUS OF HIGHLY INSULATED HOUSES – BIOLOGICAL ASPECTS -

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ABSTRACT

Since the energy-crisis of the 70'ies, the trend goes to energy-saving constructions, which have strongly changed our way of building. The development of highly insulated houses in combination with manual window-airing leads to problems concerning a good quality of the indoor air. Thus, mechanical ventilation-systems are built increasingly in detached family houses. In contrast to air-conditioning-systems there is no moisturising and cooling of the air. It can be assumed that there won't be any problems with microbial contamination.

However, the long-time-experiences and measurements, that safeguard this assumption, are missing.

The influence of the ventilation-type – mechanically or manually – on the existence of micro-organisms in the indoor air was regarded in the research-project [10].

Additionally it was checked, how the formation of mould on heat-bridges depends on the surface-material and on the indoor climate, which on the other hand is influenced by the type of ventilation.

KEYWORDS

Ventilating, Natural Ventilating, HVAC-Systems, Thermal-Bridges, Fungies

BASICS AND DESCRIPTION OF THE TEST-ROOMS

Two identical test-rooms were built in the project. The two test-rooms differ only in the type of ventilation.

Room A is equipped with a supply air vent and a simple exhaust air-ventilator. Controlled by a timer, the ventilators run two times a day for 30 minutes. A manual window-ventilation is simulated with the ventilator. It is assumed that most people aerate their apartment in the morning and in the evening since they are at work during the day.

Room B is equipped with a ventilation with cross-flow heat exchanger (KWT). The volume-flow of the supply air is regulated to 30 m^3/h. The average air-change-rate is in both rooms 0,5 h^{-1}.

The opening of the windows, to use natural ventilation of a room, is part of the user-behaviour. To guarantee the hygienic standard, a minimum-air-exchange of 10 to 50m^3/h per person is regarded as necessary (5-Recknagel et al., 1993). It can be assumed, that this is the air-quantity a person provides for himself.

Besides the requirements of the hygienic comfort, the matters of the climatic moisture control have to be taken into account. To avoid building-physical damages, like mould-attack by too high relative humidity, a minimum-outside-air-change of n=0,5 h^{-1} is necessary. (1-DIN 1946, part 6).

Studies of the actual user-behaviour, especially concerning ventilation-habits, were done by the Fraunhofer-Institut in 67 apartments (7-Reiß et al., 2001). In these studies, three different kinds of behaviours were classified:

- multi-, average- and little-airing people.

Furthermore it is distinguished from apartments

- with and without ventilation

and the room use is sub-divided respecting the ventilation-habits for

- bath, kitchen, living-room etc.

The results of the examinations can be summarised as followed:

1. The outside-air-temperature has got most influence on the opening-behaviour of the windows. The warmer it gets outside, the longer the windows are opened.
2. The influence of solar-radiation and of relative outside-air humidity is low.
3. The window-opening-duration is reduced, when wind-speed exceeds 10 m/sec.

4. Residences in detached houses show longer window-opening-duration. This can be put down to the fact that the occupation-density in apartment-houses is higher.

RESULTS OF THE MICRO-BIOLOGICAL EXAMINATIONS

During the examinations in the testing-rooms, air-germ-measurements were regularly done in the rooms as well as in the ventilation system.

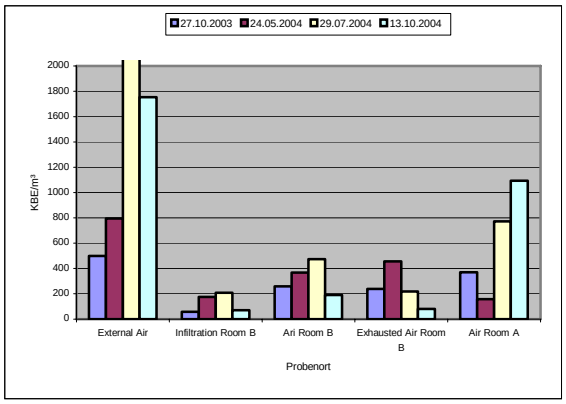

Figure 1

comparison of the air-germ-values in the summer - and autumn-months.

The values are indicated as colony-forming units (CFU/KBE) per m³ air. The increased germ-content in testing-room A, starting on 13.10.04, is due to the incipient settlement of the test-areas on the wall-surfaces. The fungi, growing on the test-areas, hand over their spores to the ambient air.

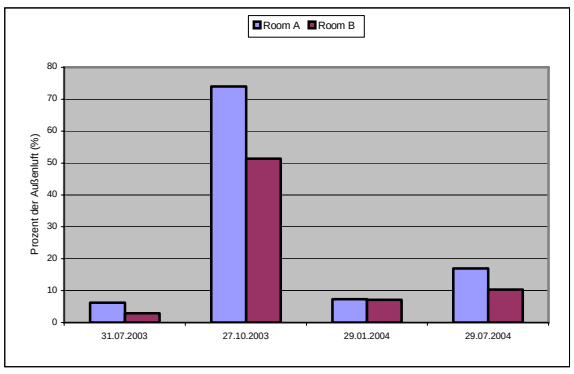

Figure 2

Germ-content of the room-air of RoomA and B in percent of the germ-content of the outside-air.

Basically, the air is quantitatively unpolluted in both rooms. As well as with a window-ventilation as with mechanical ventilation it comes to a reduction of the air-germ-numbers compared to the outside-air.

The reduction of the germ-quantity is stronger in RoomB (with ventilation) than in RoomA (window-ventilation), see Figure 2. Consequently, it can be determined that the germ-quantity in a Room is reduced stronger by a mechanical ventilation system than by a window-ventilation.

The air in RoomB contains an increased concentration of yeasts and bacteria. The spectra of species of the air in RoomA corresponds to the spectra of the outside-air. It seems that a shifting of the spectra of species is caused by the ventilation in RoomB.

The supply air filter was changed after one year and the content of Ochratoxin À and Aflatoxin was then examined (10-Toepfer and Leimer 2005). Ochratoxin À could be proved with 5 ng/gs. Aflatoxines could not be found. Aspergillus Niger and Aspergillus glaucus series (Eurotium sp.) were found in the contact-samples of the filters. They can be regarded as the producers for Ochratoxin A.

The air in both rooms can be classified as unencumbered. The concentration of air germs tends to be more inferior in the mechanically ventilated RoomB than in the window-ventilated RoomA. This leads to the conclusion that the ventilation causes a stronger reduction of air germs in the compartment air than in a window-ventilated room.

In RoomB and in the area of the ventilation, unambiguous shifts of the spectra of species in comparison to the outside-air can be seen. In RoomA, the spectra corresponds to the one of the outside-air. Therefore, ventilation can influence the mixture of the spectra of species in the compartment air. Consequently, the user is no longer exposed to the natural concentration and composition of the typical outside-air-germs. However, there is no health-risk for the user by those detected low concentrations yet. But it is not known, to what extend Mykotoxine, Allergene and other substances of fungi (e.g. b-1,3-Glucan) accumulate in the supply-air-filter and are emitted into the compartment air [10]. The fact, that Ochratoxin À was detected in the filter, shows that one should bargain for the accumulation of the life-time of the filter. Since whole, viable spores are able to pass the filter, it must even more be assumed that fragments of spores that contain both Mykotoxine as well as Allergene pass the filters because of their smaller size to a bigger extend. As a result, sensitive or allergic biased people can show reactions. The shorter the life-time of the filters is, the fewer spores and microbial metabolism-products reach the compartment air.

Therefore, regular filter-changes are sorely necessary.

MOULD-FORMATION ON THERMAL BRIDGES WITH DIFFERENT SURFACE MATERIALS

On different test-areas, which consist of artificial thermal bridges in the test-rooms it was investigated, by which circumstances in means of surface material and room- respectively surface-climate mould starts growing and how these mould contaminated surfaces affect the compartment air.

Constructive testing conditions

The artificial thermal bridges were created by cutouts in the interior thermal insulation layer. A basic plaster on lime basis was applied directly to the masonry. One of the test-areas was covered with wallpaper, the other one was painted with emulsion paint for indoor use.

Table 1

wall construction in the area of the thermal bridges

test area	construction (from outside to the inside)
wallpaper	lime silica stone basic plaster on lime basis wallpaper
Paint	lime silica stone basic plaster on lime basis lime-cement plaster emulsion

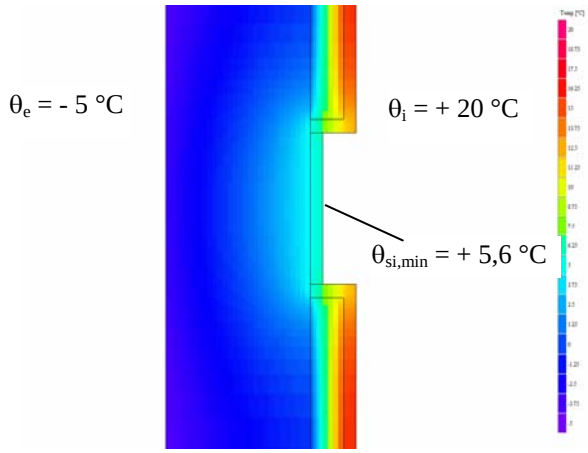

Figure 3

two-dimensional temperature-field of the artificial thermal bridge with minimal interior surface-temperature.

For a characterisation of thermal bridges in building-physical terms a temperature-factor [f_{Rsi}] is used. The temperature-factor is a non-dimensional quantifying parameter for the specific the temperature-drop in the area of thermal bridges.

In order to accomplish to the minimum requirement of thermal insulation in the area of thermal bridges according to DIN 4108-2 the surface temperature at standard living-room conditions (θi = 20 °C, φi = 50 %) must be at least θsi = 12,6 °C at the most critical point. This is the temperature at which the relative humidity at the surface is φsi = 80 %. The temperature-factor can be calculated to

temperaturefactor f_{Rsi} [-]	θ_{si}...interior surface temperature θ_i... interior air temperature θ_e... exterior air temperature
$f_{Rsi} = \frac{\theta_{si} - \theta_e}{\theta_i - \theta_e}$	$f_{Rsi} \geq \frac{12{,}6 - (-5)}{20 - (-5)} = 0{,}70$

The temperature-factors of the test-areas are at the present case:

surface of the test-area	temperature-factor f_{Rsi} [-]
1. not plastered	0,40
2. with lime plaster	0,42

Simulation of the user's behaviour

To simulate the user behaviour the testing rooms were heated and moistened.

The human being perspire moisture in dependency on his manual work. Humidity, which is produced by washing, cooking, taking a shower etc. is getting into the air. The following statements about humidity within 24 hours are common:

dispensing of water vapour	[ltr. /24h]
human being	1,0 – 1,5
Cooking	0,5 – 1,0
shower (per person)	0,5 – 1,0
drying of laundry (1machine load) – centrifuged – dripping wet	 1,0 – 1,5 2,0 – 3,5
indoor plants	0,5 – 1,0

The average of 2.5 l of water per day is emitted to the air.

Both testing rooms are equipped with an electric oil radiator with thermostat. The inside temperature can be kept at 20°C during winter. Furthermore, there is a humidifier in each of the rooms with a capacity of about 0.36l/h. These are put on twice a day for 3.5 hours (totally 7 hours) and emit a volume of about 2.5l per day to the compartment air. By this way the user and his humidity production can be simulated.

Measuring system

On the testing areas of the thermal bridges sensors have been installed to record and process the temperature of the surface and relative humidity.

Results of the microbiological surveys

During the test period samples of the surface testing areas were taken, by a sterile velvet stamp is pressed onto the and afterwards onto a solid culture medium.

For validation of fungal decay of surfaces there are no standardised requirements so far and in literature very different criteria are suggested. According to (4-Pitzurra et al. 2000), 1 CFU/cm² is regarded as a "medium fungal decay" of a stone surface.

In building biology approximate we can find requirements for bedrooms. The following approximate table are recommended for fungi decayed surfaces in bedrooms:

dispensing of water vapour	[CFU/(dm²)]
no anomaly	up to 10
light anomaly	10 – 50
strong anomaly	50 – 100
extreme anomaly	over 100
according to IBN (1999) "building-biological standards for bedrooms"	

The introduction of the Federal Environmental Agency (2002) points out, that a quantitative statement of a contact sample in forms of colony forming units (CFU) per area is not useful, as there are big fluctuations within the germ density. In this case a verbal description or photographic documentation of the affected surfaces is recommended. For this reason the results are shown in different ways.

Figure 4 + 5

Testing area "wallpaper" in Room A on October 13th and November 30th, 2004. The contamination of the area with fungi is increasing from time to time.

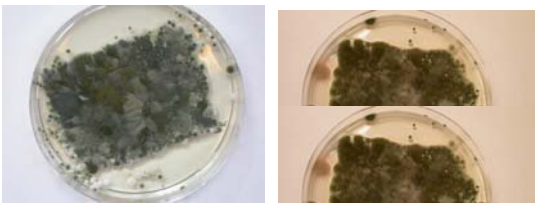

Figure 6 + 7

The contact samples of the testing area "wallpaper" in Room A on October 13th and November 30th, 2004 on malt culture medium. The samples show a thick vegetation of fungi, especially Cladosporium kinds.

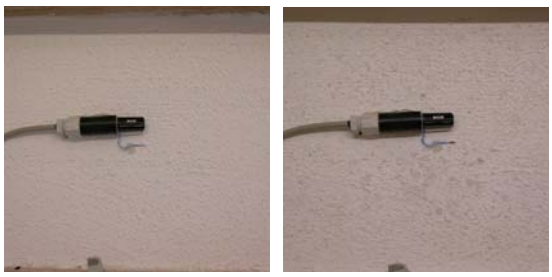

Figure 8 + 9

Testing area "paint" in Room A on October 13th and November 30th 2004. The contamination of the area with fungi increases from time to time. Altogether the size of the contamination is lower than on testing area "wallpaper".

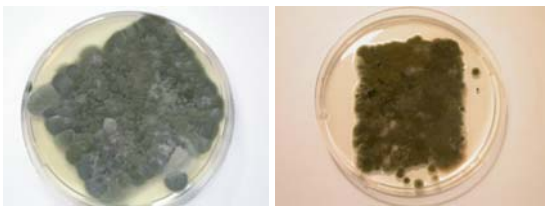

Figure 10 + 11

The contact samples of testing area "paint" in Room A on October 13th and November 30th 2004 on malt culture medium. The samples also show a thick vegetation with fungi, especially Cladosporium kinds, although the photos of both testing areas verify a much lower decay.

Figure 12 + 13

The testing areas "wallpaper" and "paint" in Room B don't show any contamination so far.

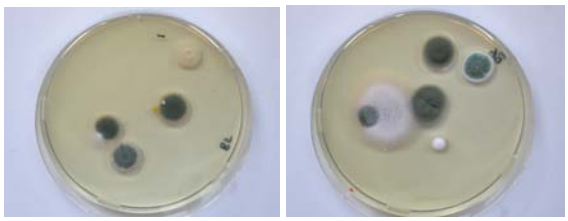

Figure 14 + 15

The contact samples of the testing areas "wallpaper" (above) and "paint" (below) of RoomB on October 13th, 2004 on malt culture medium. The contact samples of November look similar. The small amount of germs corresponds with normal background pollution.

Due to the growth density of the colony, more than 300 CFUs on the used sample size are not countable.

Both testing areas in the window ventilated RoomA show a clear fungal decay, which continuously increased in October and November 2004.

It could be seen that the density of the colonisation of testing area "wallpaper" is lower than the one of testing area "paint". Comparing the photos of both testing areas, it can be seen that the colonisation of the testing area "wallpaper" is much more intensive than then one of testing area "paint"(Figure 4+5, as well as 8+9).

Fungal decay arises mainly if there is increased humidity in the material and enough nutrients. It can be assumed that the emulsion paint contains organic aggregates, which can be seen as nutrients for fungi. The used wallpaper is manufactured by paper and pasted on with methyl-cellulose paste.

Basically, even dust deposits on a wall are sufficient as a nutrient source (11-Trautmann, 2001), so that for the long term the available amount of moistness is decisive for the colonisation.

As it can be seen on Figure 16, the temperature proportions on the surfaces of both testing areas in RoomA are similar. So there is a passing below the dew point on both areas over the same period of time and therefore there will be condensate.

The testing areas in Room B (with ventilation system) don't show any fungal decay. Comparing the temperature proportions in both testing rooms, it gets clear that intermittent window ventilation (Room A) notes stronger climatic sways than a continuous ventilation system (Room B).

Intermittent window ventilation shows a generally higher humidity of the compartment air under equal conditions for outer climatic, humidity production and daily mean air-exchange-rate. In Table 2 the ascertained dew point temperatures during the measurement-period are shown as a measure of the absolute compartment air humidity.

Table 2

Monthly average of the dew point temperature of the compartment air

month	**monthly mean temperatures of dew point of compartment air**	
	intermittent window ventilation (RoomA)	continuous ventilation (RoomB)
November 03	θ_{Tau} = 11,3 °C	θ_{Tau} = 9,8 °C
December 03	θ_{Tau} = 8,1 °C	θ_{Tau} = 6,5 °C
January 04	θ_{Tau} = 5,6 °C	θ_{Tau} = 4,3 °C
February 04	θ_{Tau} = 8,1 °C	θ_{Tau} = 7,3 °C
Mai 04	θ_{Tau} = 14,5 °C	θ_{Tau} = 12,4 °C
June 04	θ_{Tau} = 18,7 °C	θ_{Tau} = 16,7 °C
July 04	θ_{Tau} = 19,4 °C	θ_{Tau} = 17,3 °C
August 04	θ_{Tau} = 19,2 °C	θ_{Tau} = 16,5 °C
September 04	θ_{Tau} = 17,7 °C	θ_{Tau} = 14,5 °C
October 04	θ_{Tau} = 16,0 °C	θ_{Tau} = 12,9 °C

On the basis of the higher air humidity in Room A, window ventilated, the tendency to fungal decay on the predestined testing areas in the room increases. In this respect the lower air humidity can be seen as a main cause of the non-existing fungal decay in Room B.

Detailed below the periods of time when the surface humidity of the testing areas exceeds the values φ_{si} = 65 %, φ_{si} = 80 % and φ_{si} = 100 % (dew point).

Table 3

Mean exceeding time of the humidity of the surface for the testing-area with wall-paper-covering

month	**test-area with wallpaper Mean exceeding time of the surface humidity per day**

	window ventilation (RoomA)			mechanical ventilation (RoomB)		
	$\varphi_{si} \geq 65$ %	$\varphi_{si} \geq 80$ %	$\varphi_{si} = 100$ %	$\varphi_{si} \geq 65$ %	$\varphi_{si} \geq 80$ %	$\varphi_{si} = 100$ %
Dec. 03	14,7 h	9,2 h	3,5 h	15,5 h	5,6 h	2,2 h
Jan. 04	11,6 h	8,6 h	3,1 h	12,7 h	5,5 h	2,5 h
Feb. 04	15,8 h	6,1 h	1,3 h	16,4 h	6,2 h	3,1 h
Mai 04	9,5 h	3,5 h	1,5 h	7,0 h	3,4 h	0,7 h
June 04	16,9 h	6,8 h	1,7 h	17,4 h	6,0 h	1,1 h
July 04	15,9 h	8,3 h	1,9 h	15,7 h	6,2 h	1,0 h
Aug. 04	18,4 h	10,5 h	3,5 h	13,8 h	6,0 h	0,5 h
Sept. 04	23,3 h	21,0 h	9,7 h	22,5 h	13,0 h	4,1 h
Oct. 04	22,2 h	21,9 h	18,8 h	22,2 h	20,1 h	8,6 h

Table 4

Mean exceeding time of the humidity of the surface for the painted testing-area

month	**test-area with paint Mean exceeding time of the surface humidity** per day					
	window ventilation (RoomA)			mechanical ventilation (RoomB)		
	$\varphi_{si} \geq 65$ %	$\varphi_{si} \geq 80$ %	$\varphi_{si} = 100$ %	$\varphi_{si} \geq 65$ %	$\varphi_{si} \geq 80$ %	$\varphi_{si} = 100$ %
Dec. 03	15,2 h	9,8 h	4,2 h	12,2 h	3,9 h	1,7 h
Jan. 04	12,3 h	9,1 h	3,5 h	10,4 h	3,9 h	1,7 h
Feb. 04	16,5 h	7,4 h	1,7 h	12,6 h	4,9 h	1,8 h
Mai 04	9,9 h	4,1 h	1,5 h	5,5 h	2,4 h	0,4 h
June 04	17,1 h	7,1 h	2,0 h	13,2 h	3,9 h	0,3 h
July 04	16,2 h	8,7 h	2,0 h	12,7 h	3,9 h	0,5 h
Aug. 04	18,2 h	10,4 h	3,4 h	10,7 h	2,8 h	0,2 h
Sept. 04	23,2 h	20,8 h	9,5 h	19,4 h	8,6 h	2,0 h
Oct. 04	22,2 h	21,8 h	19 h	22,2 h	16 h	5,1 h

If you first of all take the surface humidity 80% r.h. as a valuation standard, which is consulted as the top threshold for moisture in DIN 4108-2, the following statements can be derived from the measuring results mentioned above:

As expected, the humidity load of the testing areas in the room with intermittent window ventilation remains longer than in the room with a continuous ventilation system.

The comparison between the testing areas is conspicuous. When ventilating permanently (RoomB) the humidity pollution on the testing area with colour lasts shorter than on the testing area with wallpaper. When window ventilating the difference is not significant. A possible reason could be the following explanation: The surface structure of colour, possibly also in connection with its less sorptive characteristics compared with wallpaper, causes a faster and better drying of the surface if ventilated continuously.

During September and October a clear rise of the exceeding time of the surface humidity with critical values can be ascertained. The beginning growth of fungi on the testing areas belongs to this period of time. A main reason for this could be the falling outdoor temperatures starting already in the middle of September in connection with the summery humidity pollution coming from the outside. Meteorologically, this phenomenon becomes noticeable as the so-called autumn fog.

The interior surface-materials are in equilibrium with the compartment air. When dispensing vapour into the room through the humidifiers, the surface-materials absorb moisture until a new equilibrium is achieved. Because of the ventilation and simultaneous or subsequent heating the relative humidity is decreased and the surface-materials emits moisture into the compartment air until an equilibrium is achieved. In RoomA the air is moistened before the ventilation in the morning and after the ventilation in the evening. Since the reception-capacity of the surface-materials is restricted, the relative humidity of the air in RoomA is increased compared to RoomB. This causes bigger condense-quantities at dew-point shortfall. As a result of the continuous operation of the ventilation in RoomB, the moisture-quantity, which is dispensed twice a day, can better be taken away.

Summarizing it can be stated, that supply with nutrients and water at the surface influence the beginning and the velocity of the colonization. Both influencing variables relativeise themselves over a longer time period.

The kind of ventilation has an influence on the relative humidity and consequently on the colonisation of the surfaces despite same average air-change-rate (0,5 h^{-1}) . Continuous ventilation can counteract mould-formation on critical surfaces, like e.g. thermal bridges.

SUMARY

Within the scope of this project [25], surveys were accomplished in two identically designed test benches, from which one of them was mechanically ventilated and the other manually aerated over windows.

The measurements of the air germs have yielded that a reduction of the germ count in the interior-air occurs independently from the ventilation-type in comparison to the outside-air. Without user interaction, it appears that the reduction is larger in a room equipped with a ventilation-system, as the reduction in a room with window-ventilation.

Within the ventilation-system and the ventilated test bench B shifts in the spectra of species were determined compared to the outside-air. These changes in the composition of the fungus-types were observed to a lower extend in the window-ventilated RoomA. It may be concluded, that a ventilation-system can lead to changes of the natural spectra of species.

The filters provided by the manufacturer are preliminary filters. The surveys have shown that fungus-spores partially are able to pass the filter. On the filters, toxinogenic and pathogenic types were determined and the mycotoxin Ochratoxin A could be detected in the filters. A long life of the filters leads to the accumulation of fungi and their metabolites. Therefore it must be reckoned that smaller particles are released in particular, which might have adverse health effects on the user.

Colonisation-experiments on artificially created thermal bridges in the test benches have shown that continuous ventilation has an effect on the room-climate indicating that a mould-formation is avoided on the surface-materials.

The detection of fungi (particularly also adverse health types) and contamination that serve as nutrients show, that a potential risk of pollution of the ventilation-systems exists. A microbial contamination can occur with increased relative humidity within the ventilation-system.

On the one hand, this can be avoided if already at design stage and under installation ease of maintenance and clean ability are guaranteed. On the other hand, a good informing of the future user is necessary. It has to be a matter of course that the filters are professionally cleaned regularly and exchanged if necessary, at the latest after one year.

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