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# Audit of low-tec ventilation systems in office buildings

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**Abstract.** This study examined ten office buildings with simplified ventilation systems. The methodology comprised a user survey, the calculation of embodied energy in terms of greenhouse gas (GHG) emissions and measurements in four of the buildings. The survey shows that in winter 35 % of the participants are satisfied with the ventilation system, 45 % are moderately satisfied (N = 553). In summer the satisfaction rate is slightly lower with 25 % satisfied and 33 % moderately satisfied (N = 458). The measurements however show that the indoor air quality regarding CO<sub>2</sub> (IDA (CO<sub>2</sub>)) in all four buildings is better in summer (all buildings are class I), than in winter (all buildings: class II). Regarding indoor environment quality and temperature (IEQ (RT)) in winter all buildings are classified category II, in summer the buildings vary between class I and III, with most of them in class II. GHG calculations show that by reducing HVAC it is possible to save up to 70 % of the embodied GHG emissions used for HVAC. By reducing ventilation alone, over 50 % of the embodied GHG emissions for HVAC can be saved.

## 1. Introduction

The present study investigates simple or simplified ventilation systems in office buildings. The aim of the project is to find out how these ventilation systems work in practice and to provide design advice for office buildings. To achieve this, ten buildings were analyzed in 2024 through site visits, a survey of building users, and short- and long-term measurements in eight workspaces (in four of the buildings). These investigations are complemented by the calculation of embodied greenhouse gas (GHG) emissions in order to assess the savings potential of simple ventilation systems compared to standard ventilation systems.

The buildings were constructed between 2004 and 2020, two buildings (NV\_man\_Z4 and NV\_man\_B1) are (partially) refurbished. The buildings provide workspace for between 20 and 1'000 people, primarily in open-plan configurations.

### 1.1. Technical concept of the buildings

Three buildings achieved the Swiss low-energy label Minergie (AirBo\_Z1 and NV\_man\_B1 / MV\_B1) or Minergie-P (TrVent\_R1). Eight buildings are actively heated, two buildings only use waste heat from equipment (Table 1). Seven buildings have a mechanical cooling system.

### 1.2. Ventilation concept

Two buildings (AirBo\_Z1, AirBo\_Z3) use exhaust air systems with waste heat recovery. Fresh air is supplied via façade-integrated air boxes (abbreviation: AirBo). Two other buildings (NV\_man\_I1/2,



NV\_man\_BI/MV\_B1) have single or multi-person offices that are ventilated naturally (abbreviation: NV\_man) during the day, while other parts of the building such as open space offices and meeting rooms, are equipped with a central mechanical ventilation system (abbreviation: MV).

**Table 1.** Office buildings, heating and cooling concept with low-tec assessment. Used abbreviations:

AC = air cooler, CAC = circulation air cooling, CCT = concrete core tempering, GBA = gross building area according to [1], GC = geothermal cooling (geothermal probe), HP = heat pump, n. a. = not available/applicable, MC = mechanical cooling, p. = panel, V = Ventilation

Assessment low-tec heating and cooling (H+C) with a full heating and cooling system as reference: - = no or low reduction (active cooling optional), ● = low reduction (e.g. heat and cooling dissipation by same system, optional cooling system), ●● = intermediate reduction (no active cooling), ●●● = high reduction (no heating and cooling system)

ID-Code / Measurement (*)	GBA (m <sup>2</sup> )	Heating	Active Cooling	Heat (H) and cooling dissipation (C)	Assessment H+C
AirBo_Z1	6'317	Geothermal probe + HP	GC + MC (HP)	CCT, small airboxes	-
MV_Z2 / NV_man_Z2	20'677	Local heat, gas	MC (chiller), cooling optional	H: Radiator + V; C (optional): V + ceiling p	- / ●
AirBo_Z3	18'363	District heating, HP	MC (chiller)	ceiling p., small airboxes	-
NV_auto_E1 *	2'698	none	none	none	●●●
NV_auto_L1	3'202	none	none	none	●●●
NV_auto_M1 *	3'531	Geothermal probe, HP	GC for CCT and MC (HP, special rooms)	H: CCT, floor heating (front desk); C: CCT, CAC	●
NV_man_Z4	4'518	Waste heat data center	MC (chiller)	H: radiator; C: partly CAC	●
TrVent_R1	1'736	HP (ground water, extract air, server)	GC	H: Ground floor: ceiling p., other: CCT, C: CCT	●●
NV_man_I1 NV_man_I2 *	4'218 7'987	HP (ground water)	GC, ground water; special rooms MC (HP)	H: CCT; C: CCT, special rooms AC	●
NV_man_B1 * MV_B1 *	9'972	District heating, HP, geothermal probe	GC and MC (chiller)	H: radiator, CCT; C: V., CCT	- / -

For daytime use and night-time cooling there is automatic window ventilation (abbreviation: NV\_auto) in three buildings (NV\_auto\_E1, NV\_auto\_L1 and NV\_auto\_M1). In NV\_man\_I1/2 and NV\_man\_Z2/MV\_Z2 automatic window ventilation is used for night-time cooling only. In building NV\_man\_Z4 there is only manual window ventilation on several floors. In addition to night-time cooling, ML\_Z2/NV\_man\_Z2 has areas with mechanical and natural ventilation, depending on the tenants' requirements. Building TrVent\_R1 has an exhaust system combined with trickle vents (abbreviation TrVent). Table 1 shows the reduction in ventilation technology.

## 2. Methodology

The online user survey was conducted in winter (08.01. – 15.02.) and summer (26.08. – 20.09.) and covers users ventilation behaviour, thermal and acoustic comfort, indoor air quality (IAQ) and user satisfaction.

The simultaneous measurements include short-term measurements (09.01. - 12.01.) and long-term measurements. The former focus on indoor environmental quality in terms of global thermal comfort (IEQ (GTC)), local thermal discomfort (LDC) and noise. IEQ (GTC) using the Predicted Mean Vote (PMV) is calculated according to SN EN ISO 7730:2006 [1] and evaluated according to SN EN 16798-1:2019 [2] with category IEQ<sub>II</sub>(GTC) as the standard ( $-0.5 < PMV < +0.5$ ). LDC is assessed according to SIA 382/1:2025 [3] with category IEQ<sub>II</sub>(LDC) as standard ( $DR < 20\%$ ). Acoustics are evaluated according to SIA 181:2020 [4], where the sound pressure level threshold for workplaces is 28 dB(A) for individual offices and 33 dB(A) for open-plan offices. The duration of the short-term measurement is approximately six hours for each building. Long-term measurements in winter (09.01. - 24.04) and summer (14.06. - 02.10.) include indoor air quality in terms of CO<sub>2</sub> concentration (IDA (CO<sub>2</sub>)), indoor

and outdoor air temperature and humidity. CO<sub>2</sub> loggers are tested with calibration gas before and after the measurement and the measurement data is corrected accordingly. Temperature, IEQ<sub>II</sub> (RT) in winter is evaluated according to SIA 382/1:2025 [3], with a range between 19.8 and 24.4 °C. The corresponding value for actively cooled buildings in summer includes a range between 22.9 and 26.1 °C. As all evaluated buildings, except for NV\_auto\_E1, have geothermal cooling, these limits are quite ambitious. IDA (CO<sub>2</sub>) is assessed according to SIA 382/1:2025 [3]. For IDA<sub>I</sub> (CO<sub>2</sub>) the absolute concentration level is < 1000 ppm and for IDA<sub>II</sub> (CO<sub>2</sub>) the absolute concentration level is > 1000 ≤ 1250. All measurement data refer to working hours Monday to Friday 8:00 to 17:00.

**Table 2.** Ventilation concepts with low-tec assessment. Used abbreviations: CMV = central mechanical ventilation, EAWHR = exhaust air system with waste heat recovery, MR = meeting room / conference room, NV = natural ventilation, OS = open space, SEA = simple exhaust air system, WHR = waste heat recovery, WVM / WVA = window ventilation, manual/automated.

Assessment low-tec ventilation: ● = low reduction (e.g. reduction of the distribution network), ●● = intermediate reduction (e.g. reduction of the distribution network and MV savings for zones), ●●● = high reduction (MV only in special zones such as rest rooms, otherwise NV)

Code	Ventilation concept	Reduction in ventilation technology	Assessment ventilation
AirBo_Z1	EAWHR: Supply air preheated / cooled via air boxes in the façade, corridors are exhaust air zones. Central extract air fan generates negative pressure. No NV	Saving ducts for supply air	●
MV_Z2 NV_man_Z2	There are areas with CMV and areas with NV only (WVM, WVA). With CMV, air is usually introduced at a central point and extracted again in the kitchenette area.	Due to CMV saving ducts for supply air, in areas with NV elimination of ventilation system	●●
AirBo_Z3	EAWHR: Air is drawn into the façade via air boxes with an integrated fan, conditioned there and brought into the room. Extraction in the same room. Central exhaust fan.	Saving ducts for supply air	●
NV_auto_E1	NV with WVM and WVA. One WVA sash per window. SEA in WC	No CMV, no heating, no cooling	●●●
NV_auto_L1	NV with WVM and WVA. One WVA sash per window. SEA in WC	No CMV, no heating, no cooling	●●●
NV_auto_M1	NV via WVA. CMV only in rooms without windows. MR have a fan or skylight	No CMV in most of the building	●●
NV_man_Z4	NV via WVM, rest rooms and copy rooms with SEA	No CMV in most of the building	●●●
TrVent_R1	SEA: Trickle vents above window. Time-controlled SEA generates negative pressure. Air volume reduced due to comfort problems. NV: WVM optional	Saving ducts for supply air	●●
NV_man_I1 NV_man_I2	NV: 1-3 wings per office for WVM + wing for WVA at night. CMV: WC, MR, cafeteria, ground floor + warehouse	No CMV in most of the building	●●●
NV_man_B1 MV_B1	CMV: OS areas and offices without external windows. NV: Offices via WVM (or possibly via open office door)	Saving on ducts for room-by-room supply air by using corridor as supply and extract zone, some offices ventilated via NV	●●

**Table 3.** Measurement instruments used in field tests. Used abbreviations: Ta = air temperature, RH, relative humidity, WP = work place

Measurement	where	Time step	Product	Specifications
Thermal comfort	WP	-	Dantec Comfort-Sense	±0.06 m/s / DR ± 0.2 °C / ±0.2K
Sound pressure	WP	-	Norsonic 140 SN1404393	Accuracy class 1
CO <sub>2</sub> / Ta / RH	WP	1 min.	Opus	±50 ppm +3 % m. v. / ±0.3 °C (0..40 °C) / ±2 % RH.
Ta / RH	outside	1 min.	MSR	±0.2 °C (+5...+45 °C) / ±2 % RH. (10..85 % RH. / 0..+40 °C)

The embodied GHG are calculated for each building including the building envelope and the internal partitions. Simplifications must be made for the HVAC systems as some specific information is not available either on the type of equipment or on the GHG. Further information can be found in [5]. Although the focus is on the ventilation concept, the heating and cooling systems are partly considered, also, because temperatures play a key role in the assessment of thermal comfort when evaluating the overall performance of the low-tech approach.

### 3. Results

#### 3.1. Survey

The survey returned 553 questionnaires in winter and 458 in summer, with a response rate between 53 % and 43 % respectively. In winter, when the windows are closed, 20 % of the users “rarely” feel draughts. When the windows are open 23 % “often” or “always” feel a draught. The temperature is rated as “agreeable” by 50 %, but 40 % find it “too cold” or “slightly cold”. Almost 60 % are “slightly satisfied” or “satisfied” with the IAQ. No significant differences are found in term of whether the building is naturally or mechanically ventilated. Noise from outside is “never” or “rarely” noticed by 80 % and noise from inside caused by the ventilation “never” or “rarely” noticed by 90 %. Two-thirds “never” or “rarely” want to influence the ventilation system. In conclusion, 35 % are satisfied with the ventilation system and 45 % are in between.

In summer, 64 % consider the room temperature as “too warm” or “warm”, while 32 % find it “agreeable”. The assessment of the group with mechanical cooling is significantly more critical than that of the group with geothermal cooling and automatic night-time cooling (Kendall-Tau-b: -0.130\*\* and 0.163\*\* respectively). There is no significant difference for the buildings relying only on passive cooling. Only 40 % are “slightly satisfied” or “satisfied” with the IAQ, with no significant differences between the ventilation concepts. Noise from outside is “never” or “rarely” perceived by 42 % (26 % “often” or “always”). Noises from the ventilation is “never” or “rarely” heard by 78 %. Only one-third “rarely” or “never” want to influence the ventilation system. About 25 % are satisfied with the ventilation system, 33 % are intermediate content.

**Table 4.** Level of contentment with indoor air quality (IAQ), temperature (T), noise exposure (NE), wish for influence on the ventilation (IV) and level of contentment with ventilation system in general (VSG). IAQ: 1 = dissatisfied , 2 = slightly d., 3 = mediocre, 4 = slightly satisfied, 5 = s.; T: 1 = too cold, 2 = c., 3 = agreeable, 4 = warm, 5 = too w.; NE, IV: 1 = never, 2 = rarely, 3 = sometimes, 4 = often, 5 = always; VSG: 1 = yes, 2 = intermediate, 3 = no.

Colour code and assessment: values over the mean = green, values lower than the mean = red. Rationale for rating: the two best/worst buildings in class get one point added/subtracted. Assessment survey: ●●● = good (+ 2 and >), ●● = intermediate (+1 to -1), ● = low (-2 to -3)

		IAQ		Temperature		Noise from outside		Influence on ventilation		Level of contentment w. vent. system		Number of answers		Assessment survey results
		Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	
ZH_01	AirBo_Z1	3.7	2.9	2.3	4.4	1.8	2.2	2.5	3.0	2.1	1.8	65	9	●●
ZH_02_01_NL	MV_NV_Z2	3.8	2.7	3.0	4.1	1.8	2.4	2.4	3.0	2.4	1.7	24	9	●●
ZH_02_02_ML	NV_man_Z2	2.9	3.2	2.5	4.1	1.6	2.5	2.8	2.9	1.8	2.0	15	13	●●
EM_01	NV_auto_E1	3.1	2.8	1.8	3.8	1.8	2.3	2.6	3.1	2.3	1.7	26	27	●●
MU_01	NV_auto_M1	3.4	3.3	2.5	3.9	1.8	2.4	2.5	3.0	2.0	1.9	53	60	●
ZH_04	NV_man_Z4	3.2	2.9	2.3	4.1	1.9	2.7	2.6	2.9	2.0	1.8	39	35	●
RU_01	TrVent_R1	3.8	3.8	2.8	3.3	1.8	2.4	2.3	2.3	1.9	2.0	8	9	●●●
IT_01	NV_man_I1	3.9	3.3	2.6	3.7	1.9	2.8	2.1	2.9	2.1	2.0	247	240	●●●
BE_01_NL	NV_man_B1	4.3	2.7	2.6	4.5	2.3	3.2	1.7	3.0	2.4	1.5	23	20	●●
BE_01_ML	MV_B1	4.0	3.3	2.6	3.9	1.9	3.3	2.1	2.7	2.3	2.1	50	35	●●●
all buildings	all buildings	3.7	3.2	2.5	3.9	1.9	2.7	2.3	2.9	2.1	1.9	553	459	

### 3.2. Measurements

Short-term: The results for the sound pressure level show that with the windows closed, the threshold values for individual and open-plan offices are met in two buildings (NV\_man\_B1, 28 dB(A); NV\_auto\_M1, 33 dB(A)). In the other two buildings, the threshold is exceeded. With the windows open, the threshold is not met in any of the buildings. Measurements in NV\_auto\_M1 in a meeting room with an exhaust fan running resulted in a sound pressure level of 48 dB(A), which is too high. In all four buildings IEQ<sub>II</sub> (LDC) is clearly exceeded with a DR of around 50 % with window ventilation (height: 0.1 m, distance from window: 1.3 - 1.5 m). This is also the case for IEQ<sub>II</sub> (GTC). Exceedances of the category are also observed for the operating temperature, PMV and vertical air temperature difference. The values gradually normalise with the windows closed and are then within IEQ<sub>II</sub> (GTC). Three buildings (NV\_auto\_M1, NV\_man\_IT2 and NV\_man\_B1 / MV\_B1) show PMV > 0.5, indicating high temperatures. NV\_auto\_E1 shows a tendency towards cooler temperatures.

Long term: In winter, mean CO<sub>2</sub> concentrations exceed 1'000 ppm in only two buildings (NV\_auto\_M1 and NV\_auto\_E1). IDA<sub>II</sub> (CO<sub>2</sub>) is fulfilled in all buildings. However, peaks around 2000 ppm are found in three buildings (NV\_auto\_M1, NV\_man\_B1 and NV\_man\_I2). The average temperature is between 22.0 °C and 23.6 °C. Temporary deviations down to 17.4 °C and up to 31.7 °C can be observed in some cases. All buildings except the outliers are in IEQ<sub>II</sub> (RT), two offices in ML auto\_M1 and NV\_auto\_E1 are even in IEQ<sub>I</sub> (RT). The average humidity is below 30% in one building (NV\_man\_B1 and MV\_B1). In summer, average CO<sub>2</sub> concentrations never exceed 1'000 ppm and IDA<sub>I</sub> (CO<sub>2</sub>) is met in all buildings. The mean values are between 520 and 700 ppm. The average temperature is between 24.1 °C and 25.5 °C. Temporary deviations as low as 17.4 °C and as high as 33.5 °C occur. Deviations towards lower temperatures are ignored for classification. For NV\_auto\_M1 one room is even in IEQ<sub>I</sub> (RT), the other in IEQ<sub>II</sub> (RT). This category is also met in ML\_man\_I2 and NV\_auto\_E1. In the building NV\_man\_B1 / MV\_B1 the rooms are in IEQ<sub>III</sub> (RT). The average relative humidity is between 49 % and 59 %.

### 3.3. Embodied energy in terms of greenhouse gas (GHG) emissions

The GHG calculations show that the values for the buildings are between 7.5 and 9.9 kg/(m<sup>2</sup>a AE), where AE is the gross sum of all heated floor areas. The HVAC contributions are between 1.1 and 2.7 kg/(m<sup>2</sup>a AE). MV\_Z2 would have a value of 3.5 kg/(m<sup>2</sup>a AE) if all tenants would opt for a mechanical ventilation and an active cooling system, which is not the case. Increased HVAC characteristics lead to higher GHG values. This is particularly noticeable for buildings with cooling systems.

**Table 5.** GHG for building (envelope and internal wall and HVAC).

Assessment GHG for V+C: ● = high GHG (> 1.1 kg/(m<sup>2</sup>a AE)), ●● = intermediate GHG (< 1.0 kg/(m<sup>2</sup>a AE)), ●●● = low GHG (<0.3 kg/(m<sup>2</sup>a AE))

ID-Code	GHG building kg/(m <sup>2</sup> a AE)	GHG heating, dissipation and electricity (H+E) kg/(m <sup>2</sup> a AE)	GHG ventilation and cooling (V+C) kg/(m <sup>2</sup> a AE)	Assessment GHG (V+C)
AirBo_Z1	7.9	1.1	1.0	●●
MV_Z2 / NV_man_Z2	8.6	1.4 / 1.4	2.1 / 0.1	● / ●●●
AirBo_Z3	7.6	1.4	1.3	●
NV_auto_E1 *	7.5	1.0	0.1	●●●
NV_auto_L1	7.9	1.0	0.1	●●●
NV_auto_M1 *	9.1	1.1	0.8	●●
TrVent_R1	9.9	1.1	0.3	●●●
NV_man_I1 / NV_man_I2*	8.7	1.1	1.0	●●
NV_man_B1* / MV_B1 *	3.7 (refurbishment)	1.4	1.2	●

#### 4. Discussion and conclusions

Measurements and survey: The results for CO<sub>2</sub> show that IAQ is of better quality in summer (all buildings IDA<sub>I</sub> (CO<sub>2</sub>) than in winter (one building in IDA<sub>I</sub> (CO<sub>2</sub>), three buildings in IDA<sub>II</sub> (CO<sub>2</sub>)). According to SIA 382/1 IDA<sub>I</sub> (CO<sub>2</sub>) refers to ≤ 17 % of dissatisfied people and IDA<sub>II</sub> (CO<sub>2</sub>) to > 17 ≤ 23 %. In winter 15 % in the measured buildings report to be dissatisfied or slightly dissatisfied with the IAQ (14 % in all buildings). This number rises up to 29 % in summer (29 % all buildings). This means that in winter the IAQ is rated better than it actually is and in summer it is rated worse than it actually is. Regarding temperature, the survey shows that buildings with a mechanical cooling are rated warmer than buildings with geothermal cooling. This cannot be verified by the measurements.

Embodied energy in terms of greenhouse gas (GHG) emissions: Some values for administrative buildings can be found in the literature. For the building envelope and internal walls, the GHG is between 4.8 kg/(m<sup>2</sup> a AE) and 8.6 kg/(m<sup>2</sup> a AE) [6], [7]. For the whole building services HVAC in [6] and [7] values between 0.9 kg/(m<sup>2</sup> a AE) and 2.9 kg/(m<sup>2</sup> a AE) are given. The building structure in this paper is between 7.5 kg/(m<sup>2</sup> a AE) and 9.9 kg/(m<sup>2</sup> a AE) and the HVAC between 1.1 kg/(m<sup>2</sup> a AE) and 3.5 kg/(m<sup>2</sup> a AE). The values are therefore within a plausible range. Reducing HVAC can save up to 70 % of the GHG used for HVAC (compare MV\_Z2 and NV\_auto\_L1). Only by reducing ventilation can more than 50 % of the GHG for HVAC be saved (comparison of MV\_Z2 and NV\_man\_Z2).

Assessment: The overall assessment of all aspects is summarized in Table 6. For the low-tech heating, cooling and ventilation concept, the embedded GHG and the survey the achievable score is 12. For the measurement of temperature and IAQ the achievable score is also 12. The best building in the first group is NV\_auto\_E1 without active heating and cooling (in NV\_auto\_L1 no survey was possible). The second-best building in this group is TrVent\_R1 with 10 points, with trickle vents which was rated quite well in the survey. As for the measurements, the building NV\_auto\_M1 received the best classification (11 points), followed by NV\_auto\_E1.

**Table 6.** Assessment of different building aspects.

Assessment measured Temperature and IDA (CO<sub>2</sub>): ● = IEQ<sub>III</sub> (RT), IDA<sub>III</sub> (CO<sub>2</sub>) ●● = IEQ<sub>II</sub> (RT), IDA<sub>II</sub> (CO<sub>2</sub>), ●●● = IEQ<sub>I-II</sub> (RT), IDA<sub>I-II</sub> (CO<sub>2</sub>)

ID-Code	low-tech H+C (Table 1)	low-tech V (Table 2)	GHG (Table 5)	Survey (Table 4)	Meas. IEQ (RT) winter/summer	Meas. IDA (CO <sub>2</sub> ) winter/summer	All
AirBo_Z1	-	●	●●	●●	n.a.	n.a.	5/12 + +/-
MV_Z2	-	●●	●	●●	n.a.	n.a.	6/12 + +/-
NV_man_Z2	●	●●	●●●	●●			7/12 + +/-
AirBo_Z3	-	●	●	n.a.	n.a.	n.a.	2/12 + +/-
NV_auto_E1*	●●●	●●●	●●●	●●	●●● / ●●	●● / ●●●	11/12 + 10/12
NV_auto_L1	●●●	●●●	●●●	n.a.	n.a.	n.a.	9/12 + +/-
NV_auto_M1*	●	●●	●●	●	●●● / ●●●	●● / ●●●	6/12 + 11/12
NV_man_Z4	●	●●●	n.a.	●	n.a.	n.a.	5/12 + +/-
TrVent_R1	●●	●●	●●●	●●●	n.a.	n.a.	10/12 + +/-
NV_man_I1	●	●●●	●●	●●●	●● / ●●	●● / ●●●	9/12 + 9/12
NV_man_I2*							
NV_man_B1*	-	●●	●	●●	●● / ●	●●● / ●●●	5/12 + 9/12
MV_B1*		●●		●●●	●● / ●	●●● / ●●●	6/12 + 9/12

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#### Co-author contribution's statement

C Hoffmann: Conceptualization, Methodology, Survey and Evaluation, Project Administration, Writing - Original Draft; C Hauri: Conceptualization, Methodology, Measurements and Evaluation, Review; A Primas: Conceptualization, Methodology, Measurements.

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