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Cross-building cooling-to-heating energy transfer

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Abstract. Nowadays office buildings are faced with high and long-term cooling demand with grate heat recovery potential. In low heating demand office buildings not all of recoverable excess heat can be utilised, so it forces to search the consumers beyond the energetic boundary of office building. One of more promising way is supplying residential building by excess heat to meet the space heating and domestic hot water demands. Proposed cross-building cooling-to-heating energy flow allows transferring and utilizing excess heat from office building in residential as a useful heat. This solution creates the flexible and sustainable environment and meets the energy challenges of the future, in line with current energy trends and policy.

1 Introduction

Nowadays office buildings are characterized by a high cooling load. During the operation hours, HVAC systems remove large amounts of heat from office spaces, technical rooms and data centres [1], losing energy by rejection into the environment. Huge amount of rejected excess heat causes surrounding thermal pollution [2] and increases the inlet air temperature, secondarily increasing the cooling demand [3], especially in urban areas.

Re-use of excess heat from office cooling is an attractive and favourable option in energetic, economic and environmental approach. Heat recovery technologies in HVAC are well known and developed in various application. The heat recovery from SC systems is limited by available heat sinks. Profitable solutions of heat recovery and usage are commonly applicate in hospitals [4], industry [5] or commercial buildings [6]. In office buildings, with low heating demand, not all of large amount of recoverable excess heat can be consumed. The excess heat overcapacity forces to search the future consumers beyond the energetic boundary of office building. Residential neighbourhood seem to be an extensive [7] and profitable consumer.

Proposed cross-building cooling-to-heating energy transfer will integrate office as a donor and residential as an acceptor building to take advantages excess heat utilization. Heat recovered in office building will be transferred to cover residential building demands: space heating (SH) and domestic hot water (DHW). Office buildings as a heat sources are usually located in high heat demand city centre and can generate excess heat in temperatures ranges suitable for residential heat supply [8]. Cross-building cooling-to-heating energy

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transfer offers high flexibility on supply and demand site. Office excess heat can supply the residential as a single heat source (covers full demand), as a part of multi heat source mix (covers part of demand) or can be rejected in overproduction periods (disadvantageous energy lost).

General overview of excess heat generation and residential heat demand profiles shows the energy potential of cross-building heat transfer (Fig. 1). The excess heat profile for typical office building is characterized by generation peaks during the operation hours (as green). Residential building profile consists the steady demand for storage DHW (as dark grey) and notable demand for SH in heating season (as grey). There are overlapped and time shifted areas of both building types energy profiles. Overlapping areas allow direct covering of residential demands by transferred excess heat. To utilize the non-overlapping heat, the energy management and balancing solutions need to be considered.

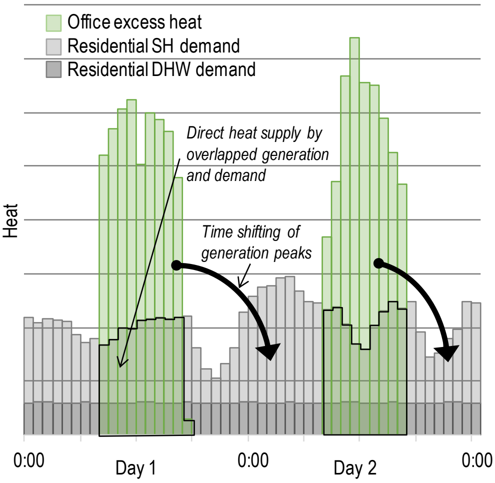


Fig. 1. Office building excess heat and residential building demand profiles for two specific days.

There are two main issues in cross-building cooling-to-heating energy transfer: 1) maximize the office excess heat transferring and consumption in residential building and 2) avoid the disadvantageous excess heat rejection. Based on defined assessment indicators specific cross-building cooling-to-heating connection modes will be developed and investigated to reach above mentioned energy targets.

2 Methods

The aim of the investigation was to test the energy potential of cross-building cooling-to-heating energy transfer based on the standardised buildings profiles. The sites were represented by the office building with excess heat from SC as a producer and by residential building with SH and DHW heat demands as a consumer. Three heat flow indicators were defined to assess the energy potential of specific cross-building connection modes: 1) the excess heat consumed in residential, 2) the excess heat needed to be rejected from office and 3) the complementary heat from local HS to cover residential demand.

To define the cross-building cooling-to-heating heat flows the yearly profiles of excess and demand heat were hourly simulated using building thermal modelling EDSL TAS software. Two variants of residential building energy standard were considered in office to residential heat transfer. First variant includes standard office building and standard residential building with SH and DHW demand. In second variant residential building was modified to low-energy standard. Buildings were simulated in accordance with the ASHRAE 90.1 [9] and ISO [10, 11] relevant specification, with local climatic conditions based on Wrocław city (Poland) data, as a central Europe location. The envelope and glazing of simulated building are shown as 3D models on Fig. 2. The annual energy performance of residential and office buildings was detailed and shown in Table 1. Due to the same net floor area the analysis results could be related to the unit area. The annual heat demand for SH and DHW of standard residential building equals the total office SC excess heat generation and amounted 133.7 kWh/(m²·a). Low-energy residential building has reduced the annual heat demand for SH and DHW by 73.8 kWh/(m²·a) which was nearly half of the standard building load.

Table 1. The annual excess heat and heat demands by end-use for all analysed buildings.

Building	Useful floor area, m²	Space cooling excess heat, kWh/(m²·a)	Heat for SH demand, kWh/(m²·a)	Heat for DHW demand kWh/(m²·a)
Office building	16 250	133.7	1.0	-
Standard residential building	16 250	no cooling	58.8	74.9
Low-energy residential building	16 250	no cooling	28.8	45.0
Office building	16 250	133.7	1.0	-

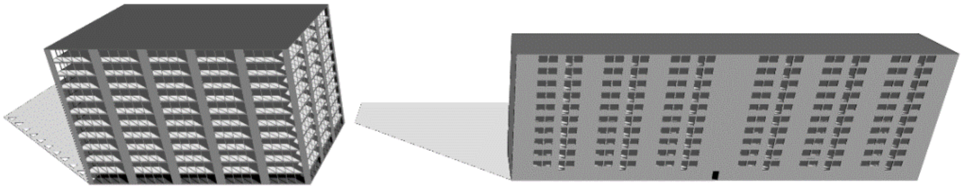


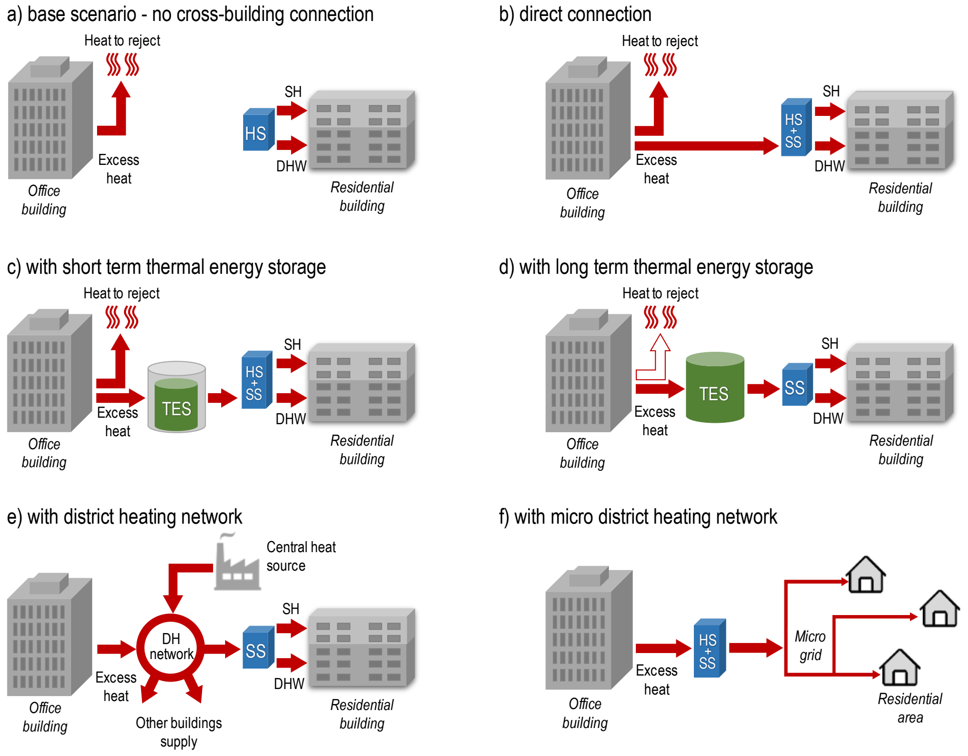
Fig. 2. Office (left) and residential (right) buildings 3D simulation models.

The essential connection modes for cross-building cooling-to-heating energy transferring was identified and analysed. Six investigated connection modes contain further improvements to maximize excess heat consumption and to avoid heat rejection. The following figures provide an overview of office to residential heat flows as a base for simulation to determine assessment indicators in specific connection modes.

In base mode analysed buildings are deprived of cross-building connection (Fig. 3a). The office building needs to reject all excess heat from SC while the residential uses the local HS to cover SH and DHW needs. The total energy consumption includes the sum of energy demands of both buildings.

Direct connection mode for cross-building cooling-to-heating energy transfer is shown in Fig. 3b. Excess heat from office building SC supplies the substation (SS) in residential building to meet SH and DHW demands. For residential building the excess heat plays the role of the primary HS. Excess heat from overlapped profiles areas could only be transferred and consumed. Unused heat from office SC must be rejected. The remaining heat demand must be covered by local HS in periods of waste energy deficit. Total energy consumption is less than the of sum energy demands in both buildings.

Fig. 3c presents semi-direct connection mode of cross-building cooling-to-heating energy transfer with short term thermal energy storage (TES) and local HS. The TES collects the excess heat to balance the office excess and residential demand. The TES capacity was defined to stored excess heat generation of the largest 24 subsequent hours. Due to the TES time shifting of heat loads more excess heat could be consumed and less of energy will be rejected. The local HS operation will be reduced. Limited storage capacity restricts the excess and demand heat balancing. The total energy consumption is lower both: than the sum of energy demands in residential and office buildings and then in cross-building direct connection mode.


a) base scenario - no cross-building connection

b) direct connection

c) with short term thermal energy storage

d) with long term thermal energy storage

e) with district heating network

f) with micro district heating network

Fig. 3. Investigated cross-building connection modes.

Cross-building heat transfer shown on Fig. 3d illustrates semi-direct connection mode with seasonal TES. The TES capacity is sized to annual balance the office excess heat generation and the residential heat demand. For building with similar annual performance TES connection mode allows transferring, storing and consuming of all excess heat. A heat rejection and local HS operation are no longer necessary. In this mode the both buildings require as much energy as only one building in a no-cross-building connection mode.

Cross-building connection through district heating (DH) network mode is shown in Fig. 3e. Integration into a fourth-generation DH network provides fully usage of excess heat as a supported by the central HS. Existing DH infrastructure is suitable to take over and distribute the excess heat. The DH system can balance the excess and demand in multiple office and residential buildings, connected into DH, at the district, city or even regional scale.

The office building can be a heat source also for small-scale customers in areas with no DH infrastructure. Cooling-to-heating energy transfer will be an in-situ heat source for low-temperature micro DH network as shown in Fig. 3f. In idealized system whole office SC excess heat is transferred into DH as a base supply for SH and DHW demand. Operation of local HS in SS complements the residential heat demands. In this connection-mode the total energy use will be locally decreased in scale of community.

3 Results

The yearly excess and demand heat profiles were defined based on EDSL TAS thermal simulation data. Dynamic simulation with hourly accounting step enables assessing the energy profiles for three investigated buildings: office, standard residential and low-energy residential. Daily data aggregation clearly presents the annual heat profiles of office and residential buildings, as is shown in Fig. 4. The A-shape excess heat profile covers only part of the U-shape SH and DHW demands directly. Thus, the direct excess heat supply is limited to overlapped areas. To maximize the excess heat consumption in residential building and to avoid the disadvantageous waste heat rejection the load time shifting is needed.

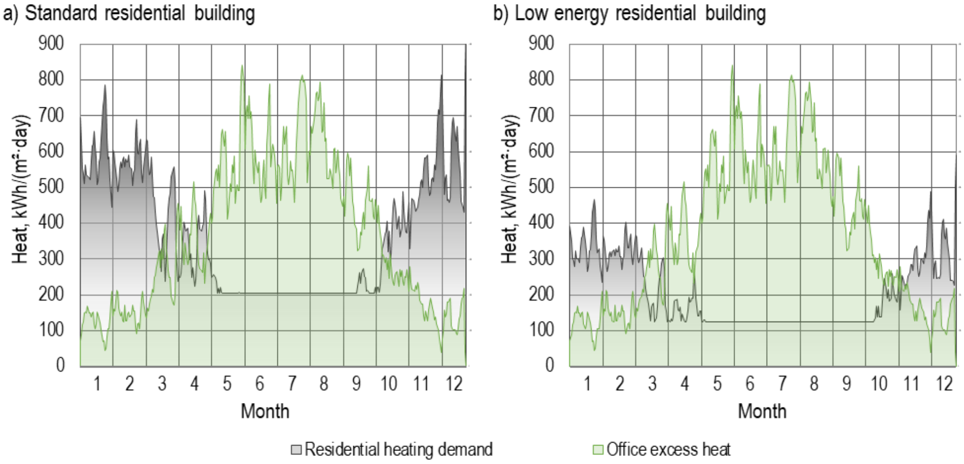
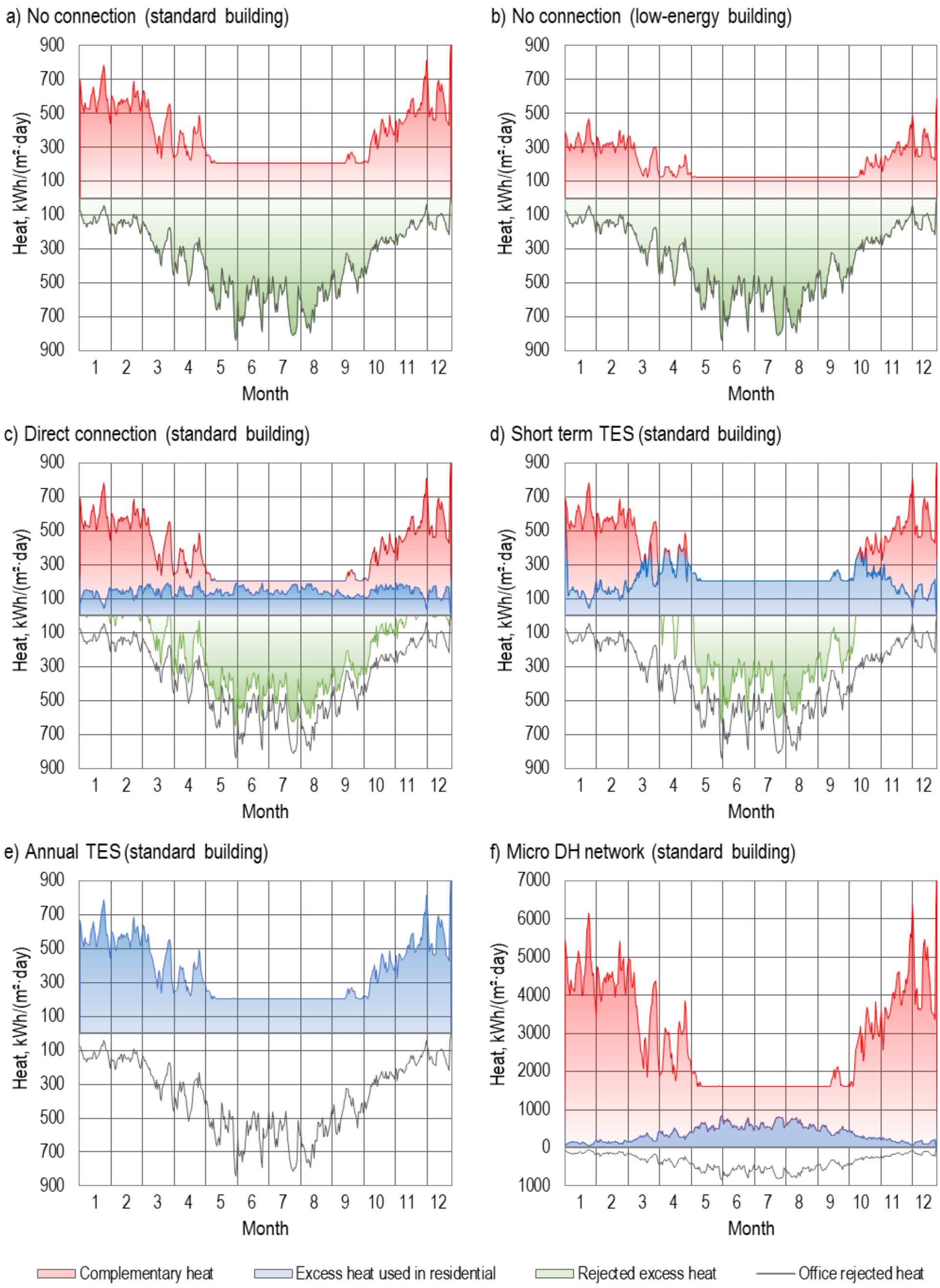


Fig. 4. Annual profiles of office excess heat generation (green) and residential heat demand (grey) daily distribution in standard (a) or in low-energy (b) residential buildings.

To illustrate the investigated cross-building heat transfers in six developed connection modes the EDSL TAS results were daily integrated. Fig. 5 shows the three assessment indicators of cross-building heat transfer: 1) excess heat consumed in residential building (blue), 2) rejected unused excess heat from office building SC (green) and 3) complementary heat from local HS in residential buildings (red).

In the Fig. 5a and 5b are shown the results for base no cross-building connection mode for two variants of residential. The no office to residential heat transfer scenario illustrates the annual profiles of excess heat generation (green area) and residential heat demand (red area). The SH and DHW loads of standard and low-energy residential buildings differ almost twice, however have analogical shapes and trends. Standard residential building load peaks to almost 813 kWh/(m²·d) and has nearly the same annual heat demand as the excess heat generated in office. The low-energy building riches the maximum of 496 kWh/(m²·d).

Simultaneously appearance of excess from office and demand in residential entail the application of cross-building direct connection. The amount of cooling-to-heating energy is clearly visible and maintain during the year almost at the same level (blue area on Fig. 5c). The mismatching of residential and office energy profiles causing the fluctuates. The daily aggregation of data allows to clearly visualisation of the trends, however affect the hourly episodes flatting. In direct connection mode the excess heat covers up to 100% of hourly residential demand. The large green area of rejected excess heat illustrates the unused potential of office cooling system as a heat source. In low-energy residential the trends are analogous, thus the next connection modes are plotted for standard residential building only.



a) No connection (standard building)

b) No connection (low-energy building)

c) Direct connection (standard building)

d) Short term TES (standard building)

e) Annual TES (standard building)

f) Micro DH network (standard building)

Fig. 5. Annual profiles of office excess heat generation (green) and residential heat demand (grey) daily distribution in standard (a) or in low-energy (b) residential buildings.

Thermal storage smoothing influence of generation and demand sites profiles. Short term TES (Fig. 5d) increases the excess heat utilisation especially in spring and autumn. The 24-hour heat storage is beneficial for the system, but limited TES capacity causes incomplete balancing of daily excess and demand peaks. The rejected excess heat was noticeably limited (green area), covering residential demands in summer (blue area). The annual TES (Fig. 5e) allows to fully use the SC excess heat in residential SH and DHW. Green area of rejected heat disappears and annual residential demand was represented by blue filling. There is no need to reject excess heat and complementary HS operation. Whole amount of waste heat was transferred and consumed in standard residential building as a single heat source.

In DH cross-building cooling-to-heating connection mode district network takes over and distributes all excess heat generated in connected office building. The integrated office buildings become a part of multi-source district heating system.

Micro-grid (Fig. 5f) according to assumptions are based on excess heat as a primary energy source. The high of residential demand profile will overlap each of the hourly excess peak. On daily scale chart the residential heat demand seems to be much lower than the SC excess. All generated excess heat from office SC will be locally transferred and consumed in-situ. The office SC excess heat (blue area) was complemented by the local HS operation (red area) eliminating heat rejection (no visible green area).

The three assessed indicators allow evaluating the energy effect of cross-building cooling-to-heating energy transfer both on demand and supply site. On demand site, based on simulation data, the annual proportion of consumed excess and complementary heat were defined and assessed (Table 2).

Table 2. The annual excess heat and heat demands by end-use for all analysed buildings.

Indicator	Residential building	No connection	Direct connection	Short term TES	Seasonal TES
Excess heat in residential demand	SB	0.0%	38.9%	57.4%	100.0%
	LEB	0.0%	46.3%	73.4%	100.0%
Complementary heat in residential demand	SB	100.0%	61.1%	42.6%	0.0%
	LEB	100.0%	53.7%	26.6%	0.0%

In no connection mode whole excess heat was rejected and wasted. In direct connection mode the simulation data provides the annual share of excess heat in residential demand at the level of 38.9% and 46.3% for standard (SB) and low-energy (LEB) residential building respectively. The rest of uncovered demand was complemented by local HS operation, supplying 61.1% (SB) and 53.7% (LEB) of annual SH and DHW. The hourly simulation shows up to 100% coverage of residential demand by excess heat in overlapping periods. In remaining time, the SH and DHW were supplied by local HS or by excess and HS mix. Short term TES increases share of excess heat in residential demand. The 57.4% (SB) and 73.4% (LEB) of annual heat demand was covered by excess heat from office building SC. The rejected heat was favourable limited from one-third (SB) to almost twice (LEB). Simulation of annual TES connection mode shows full covering of SH and DHW demand by excess heat. Due to time shifting of long term storage the excess heat covers 100% of residential demand both in SB and LEB. The district heating and micro-grid connection modes allow transferring and utilizing all excess heat generated in office building SC for both residential building variants.

Application of simple direct connection mode contribute to 38.9% (SB) and 46.3% (LEB) energy benefit. Implementation of short-term TES intensifies the excess heat utilisation by 18.5% (SB) and 27.1% (LEB) in relation to the direct connection. The TES extension to the annual accumulation level provides the independence of additional heat source required in SB and LEB. Accomplishment these requirements have much greater involvement with comparable profits than transition from standard to direct or from direct to short-term TES modes.

Despite almost two-fold annual demand reduction changing from standard to low-energy building not increase the excess energy share of twice. In the direct connection mode, the share of waste heat growth only 7.4% and in short term TES 16.0%. In annual TES connection mode, the whole SH and DHW demands were covered by excess heat with the waste heat overproduction in low-energy building variant.

The percentages of rejected excess heat on supply site are shown in Table 3. No connection mode precludes the cross-building heat transfer and whole generated excess heat needed to be rejected and wasted. In direct connection mode, due to non-overlapping profiles, up to 61.2% (SB) and 74.7% (LEB) of generated excess heat was unused and lost in rejection process. Short term TES application decreases the untransferred heat rejection on generation site for 43.1% (SB) and for 60.1% (LEB). In office to standard residential building connection mode the annual TES allows overtaking, storing and transferring 100% of excess heat generated in office building. In low-energy building supply until 44.8% of available excess heat was rejected, due to the small SH and DHW needs regarding to available excess heat value. The surplus heat can be transferred to supply next low-energy residential buildings.

Table 3. Assessment indicator for supply site.

Indicator	Residential building	No connection	Direct connection	Short term TES	Seasonal TES
Unused and rejected excess heat	SB	100.0%	61.2%	43.1%	0.0%
	LEB	100.0%	74.7%	60.1%	44.8%

Presented results forms the connection-modes ranking in energetic approach. The developed assessment methods, based on annual simulations, can be easily extend by next indicators related to environment, economic, building services, district infrastructure or other local factors and conditions. The specific set of assessment indicators determines the ranking and best solution of cross-building connection modes.

4 Conclusions

The study revealed large energetic potential of cross-building cooling-to-heating energy transfer, as a favourable heat source for residential buildings. In excess heat abundant cities cross-building connection will integrate office donor and residential acceptor buildings to beneficial waste heat transferring and consumption beyond the donor building energy boundaries. Office buildings are an excess heat sources usually located in high heat demand city centre.

Simulation results show energy profits in every cross-building connection mode. The share of excess energy in residential demand varies according to applied connection mode, energy standard and energy profiles of integrated buildings. The basic direct cross-building connection is already beneficial and technical developments in heat transferring improve the energy effect. Energy standard of supplied building affects the supply and demand site. On demand site the low-energy standard of residential building increases the share of excess heat in annual demand for all investigated connection modes. On supply site lower residential demand limits the excess heat utilisation and forces energy losses in waste heat rejection. On other site it creates opportunity to supply the next residential buildings.

Based on presented assessment indicators the most favourable connection mode can be determined depending on expected energy effects and local conditions. The indicators methodology could be also extended to include ecological or economic issues. Energy and environmental benefits of excess heat utilisation are convergent. Cross-building heat transferring reduces or even eliminates operation of conventional heat sources for residential SH and DHW supply. The environmental impact will be double-reduced in the emission mitigation and no-thermal pollution.

The proposed connection modes for cross-building cooling-to-heating energy transferring are high applicable. Cross-building cooling-to-heating transfer can be applied in existing, refurbished and new constructed buildings. Cross-building connection creates the flexible and sustainable environment for excess heat transferring and utilization in integrated buildings of different function, as a local heat linking and neighbourhood energy community.

Proposed energy linking can be applied as an island energy system or as a part of small or large scale energy system including multi-source and smart grid technologies. This solution meets the energy challenges of the future, in line with current energy trends and policy. This concept should be submitted by holistic framework of multi-functional masterplaning and should be considered in all excess energy abundant locations, especially in urban and DH areas.

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