Economic and emission reduction potential of renewable based energy systems in an apartment building in cold climatic conditions

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Abstract

Buildings are one of the largest contributors towards emissions. The EU countries plan to cut 80% of the emissions by 2050. The aim of this article is to model two different photovoltaic (PV) based energy systems integrated either with new or old building in a district and to conduct emissions comparison against a reference city level energy system in the Nordic region. The main novelty lies in the analysis of the CO_2 reduction potential from the grid and buildings. The relative emissions reduction is found to be 85% when the new building is integrated with PV+heat pump and seasonal storage system compared to the reference energy system. The emission reduction cost of such a system is 8.59 €/kg CO_2/yr. Such systems can support in reaching the EU's emissions target.

Key Innovations

- PV with air source and water source heat pump integrated with seasonal storage energy system can be used to reduce emissions from the old and new buildings simultaneously.
- When the reference city level energy system is replaced by the renewable energy system (PV with air source and water source heat pump) with seasonal storage, the emissions from the old building is reduced by 69%, and the emissions from the new building is reduced by 63% The emission reduction cost varied from 10.49 to 27 €/kg CO_2/yr.
- Emissions from the old building can be reduced by 85% when it is retofitted or replaced according to the new building standards and it is integreated with the renewable based and seasonal storage energy system.
- The onsite energy fraction varied from 48% to 83% depending on the building type and energy system case.

Practical Implications

Buildings and communities' energy studies should focus on emission minimization and cost reduction rather than energy minimization. This will result in economically feasible and carbon neutral energy systems that are in line with the EU long-term strategy of 2050.

Introduction

Climate change has been the challenge that the world has been facing. This issue has pushed the society to address this challenge. The European Union (EU) have issued regulations that aim to reduce the emission by 80% by 2050 compared to the 1990 levels (European Commission, 2019).

According to the Energy Performance of Buildings Directive (EPBD) (European Commission, 2010) all new buildings have to be nearly zero energy building by 2020. Most of the building stock are old and therefore, they are inefficient in terms of use of energy. Buildings contribute towards large emissions (Moore, Horne, & Morrissey, 2014). For example, in Greece 70% of the buildings are built before 2010 (Chadiarakou & Santamouris, 2015). In Finland around 43% of the buildings were constructed before 1980 (Holopainen, Milandru, Ahvenniemi, & Häkkinen, 2016). The Finnish regulations target is to reduce 80% of the emissions by 2050 (Ministry of the Enviornment, 2019). Residential buildings are one of the largest building segments in the Finnish building stock. There is large potential in old buildings to improve the efficiency and reduce the emissions via renovation in Finland (Hirvonen, Jokisalo, Heljo, & Kosonen, 2019). Moreover, the building renovation solutions and renewable energy integration methods are different in different climatic conditions (Rehman, 2018). The present study focuses on old apartment buildings constructed in 1970, to show the emission reduction potential in the Finnish climate. These buildings are selected as large building stock exist that were constructed during 1970-80s and undergoing renovation. In addition to this, new building is also taken as a case study to show the emission reduction potential from the new buildings along with the old building.

Renewable energy is use to reduce emissions. In this respect, Germany is planning to increase the use of renewable energy by more than 90% (Henning & Palzer, 2014). In Finland 85% of the electricity is generated by carbon free sources (Finnish Energy, 2016). The challenge in the Finnish environment is the decarbonisation of the district heating systems where 37 TWh of heat is produced for district heating and 46% of the heating demand is met through it (Energiateollisuus, 2019). The energy mix to produce heat is coal, gas and peat (Finnish Energy, 2016). The average CO_2 emissions emitted by the district heating in Finland is around 176 g

CO_2/kWh (Finnish Energy, 2016). To reduce the emissions, the district heating system has to be renovated in order to reach the emission reduction target (Ministry of the Environment, 2019). Therefore, the focus in the present study is to reduce the emissions from the building caused by the energy use, especially in the context of heating of old and new buildings in the district.

Solar energy can be used as a renewable source that can assist in reducing the emissions in Finland (Global Climate and Energy Project (GCEP), 2017). However, for solar-based solutions, the challenge in the Finnish conditions are: 1) the seasonal mismatch between energy demand and generation and 2) the economic issues (Rehman, 2018). PV can be used to produce heat as well. Moreover they are economical compared to solar thermal (Franco & Fantozzi, 2016). PV can be to run a ground source heat pump (GSHP) to produce heat to meet the heating demand of a building, while excess heat can be stored in a seasonal storage. There is lack of studies on this concept where PV is integrated with heat pump and seasonal storage used to provide heat in the Finnish climate. In addition to this, there is a lack of study on the CO_2 emissions reduction, implementing this concept in Finnish conditions.

The issue of seasonality in Finnish conditions can be solved using energy storage especially seasonal storage. Different types of storages can be used to store the solar energy as sensible heat as it is less expensive compared to the other types of storage such as batteries and phase change materials (Rehman, 2018). A pilot study carried out in Canada shows that solar thermal collector can provide 98% of the space heating through solar energy, this pilot study has borehole thermal energy storage (BTES) integrated with the collectors (Beausoleil-Morrison, Kemery, Wills, & Meister, 2019). In the present study BTES is used as seasonal storage as it is flexible in term of location, simple design and better ground conditions in Finland (Rehman, 2018).

In earlier studies (Cao, Hasan, & Sirén, 2013) focus has been either on the building level energy efficiency or on the energy system modelling separately. Moreover, the technical or economic performance are mainly considered. The novelty in this study is a multi-dimensional approach where both new and old buildings are integrated with renewable based energy system in Finnish climatic conditions and their environmental and economical performances are discussed. The energy system is designed to meet the heating and electrical energy demand of the buildings. The aim of the study is to evaluate the emission reduction potential, the life cycle costs, imported electricity and onsite energy fraction from the old and new building.

Methodology

Buildings details

The old and new apartment buildings are situated in the Helsinki region in southern Finland area. Here onwards it is referred as building. The old building under study is built during 1970s (Hirvonen et al., 2019). While the new building under study is planned to be constructed by 2021 under the Horizon Europe 2020 'EXCESS' project (Ala-Juusela et al., 2020). Both buildings have floor area of 4000 m^2. There are around 52 apartments and 7 floors. There is no retrofitting done on the old building (OB). The new building (NB) has better passive design. This is because it includes better insulation, windows and efficient heat recovery.

The buildings are modelled using IDA Indoor Climate and Energy (IDA-ICE) simulation software (EQUA Simulation AB, 2018). The details about the old building (OB) are discussed in (Hirvonen et al., 2019), while the details about the new building (NB) are discussed in (Ala-Juusela et al., 2020). The cost of the old building is assumed to be '0' and any improvement in the building performance is given as the difference from this zero reference cost. Both buildings are compared to evaluate the emission reduction potential relative to the investment on the building. Table 1 shows the energy demand and the design values of the two types of the buildings used in the study. The domestic hot water (DHW) demand is assumed to be 35 kWh/m^2/yr (Ministry of Environment, 2011). The electricity demand of the OB and NB is assumed to be 36.9 kWh/m^2/yr (Ala-Juusela et al., 2020). Space heating demand depends on the type of the building, while electricity demand is kept same for both OB and NB in this study. The components installed as shown in Table 1 are regarded as building level installation. This installation and costs are considered separate from the centralized renewable energy system that is under study.

Table 1: Old building and new apartment building space heating demand and the building envelope thermo-physical properties (Ala-Juusela et al., 2020; Hirvonen et al., 2019).

Building type	**Space heating demand (kWh/m²/yr)**	**U-value (W/m² K)**		
		Ext. Walls	**Roof**	**Windows**
Old building (OB)	129	0.81	0.47	1.7
New building (NB)	15	0.14	0.09	0.88

Building's energy system details

- Case 0: City level energy system (Reference case)

In case 0, the city level energy system, i.e. district heating and electrical grids, are integrated with either the old or the new apartment building. The reference case energy system is shown in Figure 1. There is no renewable energy source or storage in this case. The demand of the building is met via the district heating and the electrical girds by importing the energy as shown in Figure 1. In case 0, only the buildings are changed i.e., either OB or NB. This is done to analyse the effect on the CO_2 emission reduction and costs due to the change in the building envelope as shown in Table 1. The DHW is provided at 60 °C and the space heating (SPH) temperature varied from 27 °C and 45 °C based on the outdoor temperature (Rehman, 2018). The same set points are used for other case studies.

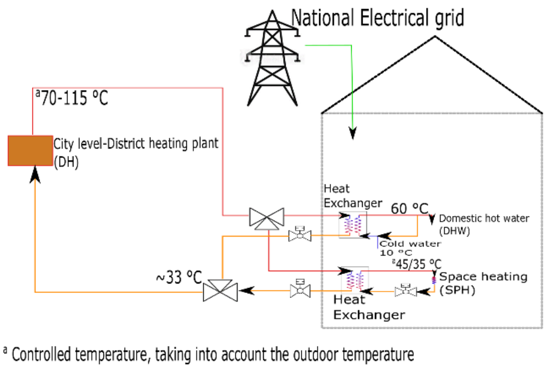

Figure 1: The schematic diagram of the reference city-level district heating and electrical grid (Case 0).

- Case 1: PV with ground source heat pump based centralized energy system

In this system, PV panels are installed on the roof of the building to provide heating and electrical to the building. The proposed energy system is integrated with the old and new residential building. The schematic representation of the PV+ground source heat pump based energy system for the OB and NB buildings is shown in Figure 2.

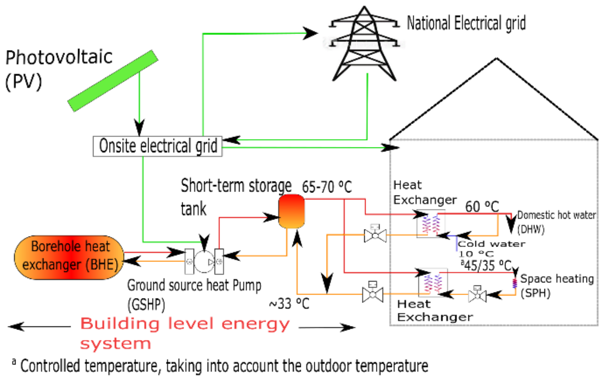

Figure 2: The schematic diagram of the centralized photovoltaic (PV) and ground source heat pump (GSHP)-based heating and electrical system integrated with OB and NB buildings in the district (Case 1).

In case 1, PV is used to generate heat using the GSHP. The GSHP based heating system is popular in Finland using grid electricity. On the contrary, PV can be used to operate the GSHP to produce heat energy, rather than using grid electricity (European Heat Pump Association, 2018). The GSHP is used to heat the short-term storage tank to 62 ºC if the tank temperature is lower than 58 ºC. The GSHP takes the energy from the borehole heat exchanger (BHE) to charge the tank. The tank is used to provide the SPH and DHW to the building, where backup electric heater is also installed if system is not able to meet the remaining heat demand. The PV is also used to provide electricity to the electrical appliances in the building. Any excess electricity is exported to the grid, while any shortfall is imported from the grid. Similar approach is used in the other cases.

- Case 2: PV with air-to-water heat pump, water-water heat pump and borehole thermal energy storage based centralized energy system

Similar concept as in case 1 is further improved to propose a novel energy system and control strategy for case 2. The novelty in case 2 is in the controls and integration of different storages, generation components and seasonal storage for the OB and NB in the district. The schematic representation of the case 2 is shown in Figure 3.

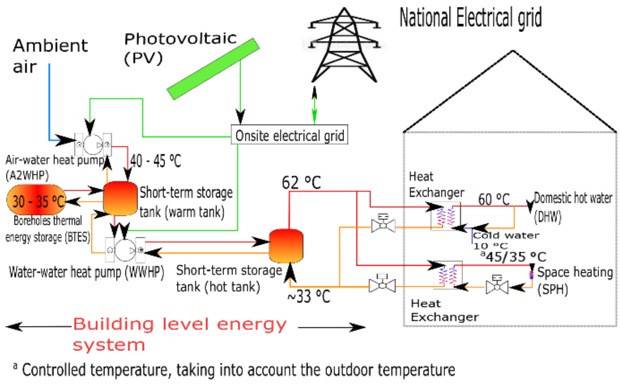

Figure 3: The schematic diagram of the centralized photovoltaic (PV), air to water heat pump (A2WHP), water to water heat pump (WWHP) and boreholes thermal energy storage (BTES) -based heating and electrical system integrated with OB and NB in the district (Case 2).

The PV is used to produce electricity. Firstly, this electricity is provided to the water-water heat pump (WWHP) to charge the hot tank at higher temperature. Secondly, the remaining electricity is then used to run the air to water heat pump (A2WHP) to charge the warm tank at lower temperature. Thirdly, the remaining electricity after running the WWHP and A2WHP is then provided to meet the electrical appliances demand of the building. After that, any remaining electricity is exported to the grid, while any shortfall is imported from the grid. The A2WHP is used to charge the warm tank at 40 ºC, if the tank temperature is 5 ºC higher than the BTES (seasonal storage), the BTES is charged from the warm tank. The WWHP is used to charge the hot tank at 62 ºC by taking energy from the warm tank. The DHW and SPH is provided through the hot tank and backup electric heater is also provided.

Energy system simulation: TRNSYS

The energy systems are modelled using TRNSYS simulation software. The emissions, life cycle costs (LCC) and technical performance of the systems are compared. The weather data is used from TRNSYS (Meteonorm) (University of Wisconsin, 2017). The energy system's complexity and required simulation time depend on each case study. For instance, the case 1 is simple as it has building data, heat pump and BHE and it took around 2-3 minutes for each scenario. On the other hand, case 2 is complex as it has building data, heat pumps, tanks and BTES. Therefore, it took around 12 minutes for each scenario in case study 2.

Emissions

The average emission from the district heating network in Finland is around 176 kg CO_2/MWh (Finnish Energy, 2016). Compared to the electricity these emissions are relatively high. This is because for district heating fossil-based fuels are used at city level. This emission is used for district heating in the reference case 0 and it does not vary during the year. On the other hand, for electricity, hydro, nuclear and imported electricity is used therefore it has lower emissions compared to district heating (Fingrid Oy, 2020). Figure 5 shows the average monthly emissions from the electrical grid (Finnish Energy, 2016). The emissions calculated in the study is based on electrical grid emissions, as this is the only component that is imported from the grid side for OB and NB. The export of electricity to the grid is not considered to mitigate emissions for the import of electricity. The study shows how solar energy can assist in reducing emissions associated with energy import by the apartment building from the grids.

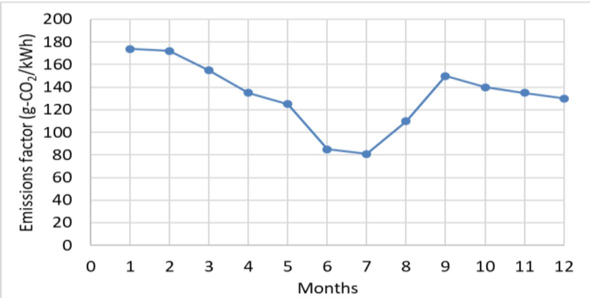

Figure 5: The emissions from the electrical grid in Finland.

Energy and life cycle cost calculations

The parameters calculated are CO_2 emissions, imported electricity and life cycle cost (LCC). CO_2 emissions are of interest for policy makers while costs are of interest for investors. The purchased electricity is calculated as(Rehman, 2018):

$$E=E_{PV}-(E_{HP}+E_{AUX}+E_{BUI}) \quad (1)$$

Where, E is imported electircty when it is negative and E is exported electricity when it is positive, E_{PV} is the electricity produced by PV, E_{HP}, E_{AUX} and E_{BUI} are the electricity demand of the heat pumps, backup heater and electrical appliances demand, respectively.

The LCC is calculated in simplified way (net present value NPV) and it is the difference in the LCC between the reference case and the added components including the investments cost of the PV, air to water and water to water heat pumps, tanks storages, BTES, building level costs and operational cost depending on the system type (Rehman, 2018). The imported electricity price used is 11.1 c/kWh and the exported electricity price used is 4.04 c/kWh (Nord Pool As, 2016). The electricity price includes the taxes and distribution cost. The interest rate of 3% and electricity price escalation rate of 1% is used (EUROPEAN COMMISSION, 2012). The disposal and maintenance costs are not included. The LCC is calculated for the 25 years. The design variables values and the costs at the building and centralized energy system levels are shown in Table 2.

Table 2: Design parameters and costs.

Case	Design variables	Values	Investment cost	References
			Reference city level energy system	
0	Apartment building type	Old building (OB), SPH = 129 kWh/m²/yr	0 (Building cost)	(Hirvonen et al., 2019)
	Apartment building type	New building (NB), SPH = 15 kWh/m²/yr	192 €/m² (Building cost)	(Hirvonen et al., 2019)
			Centralized energy system level cost	
1	Monocrystalline PV (m²)	2000	215 €/ PV m²	(Hirvonen et al., 2019)
	Storage tanks (m³)	15	936 €/m³	(Hirvonen et al., 2019)
	Water-water heat pump (60 kW$_{thermal}$/unit each)	4-5	325 €/kW thermal	(Hirvonen et al., 2019)
	BTES height ration	1.5	33 €/m (drilling)	(Rehman, 2018)
	BTES density (boreholes/m²)	0.04		
			Centralized energy system level cost	
2	Monocrystalline PV (m²)	2000	215 €/ PV m²	(Hirvonen et al., 2019)
	Storage tanks (m³)	70	884 €/m³	(Hirvonen et al., 2019)
	Storage tanks (m³)	70	884 €/m³	(Hirvonen et al., 2019)
	Water-water heat pump (60 kW$_{thermal}$/unit each)	2	325 €/kW thermal	(Hirvonen et al., 2019)
	Air. water heat pump (16 kW$_{thermal}$/unit each)	13	425 €/kW thermal	(Hirvonen et al., 2019)
	BTES height ration	1	33.5 €/m(drilling) + 3 €/m³(excavation for insulation) + 88 €/m³ (1.5 m insulation thickness)	(Rehman, 2018)
	BTES density	0.15		
	BTES volume (m³)	30000		

The design variables values are based on the optimized value as calculated in (Rehman, 2018). Moreover, the design variables are selected using parametric study so that the energy systems can meet the required temperature level for SPH and DHW as discussed above. The values are kept close to each other in all the cases 0, 1 and 2 in order to provide close comparison. However, in some cases these values change due to the requirement for each case to meet the required set points for SPH and DHW as discussed.

Results and discussion

Case 0: Reference case city level energy system

Figure 6 shows the building type i.e., OB and NB on the x-axis and the energy demand, LCC and the CO_2 emissions on the y-axis are in for case 0. It can be observed that the LCC of the OB building is 4% lower compared to the NB building (blue bar). This is because higher investments are needed in the NB due to better insulation, windows and heat recovery. Due to better performance of the NB, the district heating demand is lower for NB compared to OB (red bar). The electrical demand is constant in both OB and NB. The district heating demand reduced from 164 kWh/m^2 in OB case to 50 kWh/m^2 in NB case. Due to the reduction in the district heating demand, the CO_2 emission is reduced from 33 kg CO_2/kWh/m^2 to 14 CO_2/kWh/m^2 (green line). The emissions are 57% lower in this case, where NB is used with the city level energy system (case 0) compared to the OB. It can be observed that by investing at the building level efficiency, the emissions can be reduced.

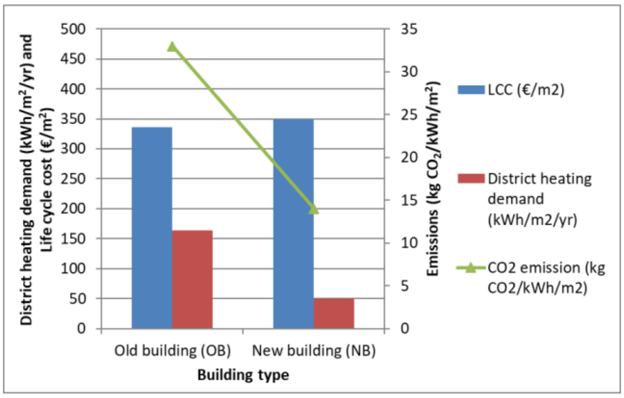

Figure 6: The energy demand of the building, LCC and CO_2 emissions for the Case 0.

Case 1: PV with ground source heat pump based centralized energy system

Figure 7 shows the purchased electricity, LCC, and emissions for case 1. It can be observed in Figure 7 that the purchased electricity is reduced by 67%, i.e. from 149 kWh/m^2 to 48 kWh/m^2 (red bar), when NB is integrated with case 1 instead of OB. The LCC also increases from 372 €/m^2 to 425 €/m^2 (blue bar in Figure 7) when NB is integrated with the case 1. Because of increased LCC and reduction in the purchased electricity, the emissions also reduced when NB is used compared to the OB building in case 1 (green line in Figure 7). The emissions are reduced by 53% when NB is integrated with case 1 compared to OB. The emissions reduced from 15.2 kg CO_2/m^2 to 7.1 kg CO_2/m^2. Compared to reference case 0 (Figure 6) it can be observed that for both the building types i.e., OB and NB, the emissions are lower in case 1. This is because the centralized energy system can meet the demands of the building and at the same time able to reduce the import of energy from the grid, resulting in lowering the emissions. Compared to case 0 the emissions are reduced by 54% for OB building type in case 1. Similarly, compared to case 0 the emissions are reduced by 49% for NB building type in case 1. However, compared to case 0, the LCC of case 1 is higher, as additional investments are needed for the centralized energy system.

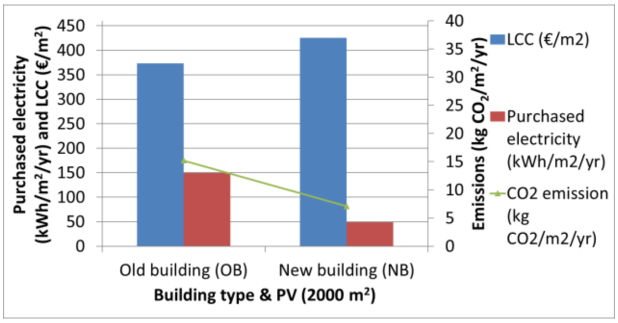

Figure 7: The purchased electricity, LCC and CO_2 emissions Case 1.

The LCC cost breakdown and the onsite energy fraction of case 1 is shown in Figure 8. It is found that the overall cost of the case 1 is higher when NB is integrated with the centralized energy system compared to the scenario when OB is integrated. It is observed in Figure 8 in OB scenario that 53% of the cost goes to the energy cost, and 47% goes as investments in the centralized energy system cost. On the other hand, in NB scenario that 15% of the cost goes to the energy cost, 45% goes to investments in the building level cost and 40% goes to investments in the centralized energy system cost. Lastly, in case 1, the onsite energy fraction increased from 48% in OB building scenario to 70% in NB building scenario.

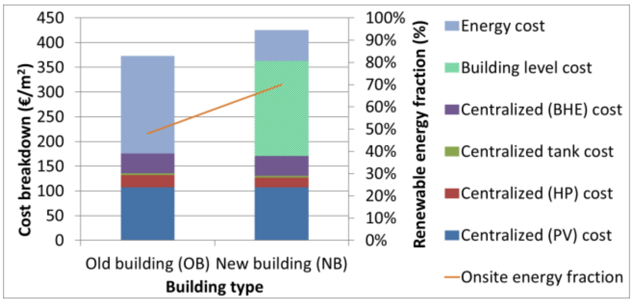

Figure 8: The LCC cost breakdown and onsite energy fraction of Case 1.

Case 2: PV with air and water source heat pump based centralized energy system integrated with seasonal storage

Figure 9 shows the purchased electricity, LCC, and emissions for case 2. It can be observed in Figure 9 that the purchased electricity reduced by 43% i.e., from 62 kWh/m^2 to 35 kWh/m^2 (red bar), when NB type is integrated instead of OB. The LCC also increases from 345 €/m^2 to 481 €/m^2 (blue bar) when NB is integrated instead of OB. Because of the increased LCC and reduction in the purchased electricity, the emissions are reduced by 50% when NB is integrated compared to OB (green line in Figure 9). The emissions are reduced from 10.2 kg CO_2/m^2 to 5.1 kg CO_2/m^2. Compared to the reference case 0 (Figure 6) and case 1 (Figure 7), it can be observed that for both the building types, OB and NB, the emissions are lower in case 2. This is because the centralized energy system with seasonal storage can meet the demands of the building and at the same time able to reduce the import of energy from the grid, resulting in lowering the emissions. In case 2, the purchased electricity reduced by 60% and 27% for OB and NB type, respectively, compared to case 1. Compared to case 0 and case 1 the emissions are reduced by 69% and 32%, respectively, for OB building type in case 2. Similarly, compared to case 0 and case 1, the emissions are reduced by 63% and 27%, respectively, for NB building type in case 2.

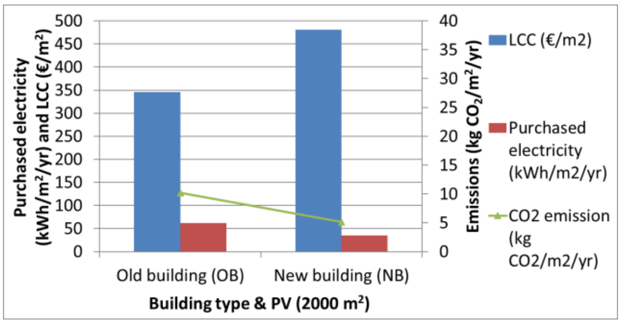

Figure 9: The purchased electricity, LCC and CO_2 emissions for the Case 2.

The LCC cost breakdown and onsite energy fraction of case 2 is shown in Figure 10. It is observed in Figure 10 that there is an additional cost for BTES, which is not in case 0 and in case 1. Due to the BTES, the cost of the centralized energy system is higher compared to the case 0 and case 1. However, due to the integration of BTES in case 2 with OB, the energy cost is reduced from 336 €/m^2 in case 0 to 106 €/m^2 in case 2. Similarly, the energy cost can be further reduced in case 2 from 158 €/m^2 in case 0 to 50 €/m^2 when NB is integrated. The onsite energy fraction can be increased from 48% in case 1 with OB to 70% in case 2 with OB. On the other hand, the onsite fraction with NB can further increased from 70% in case 1 to 83% in case 2.

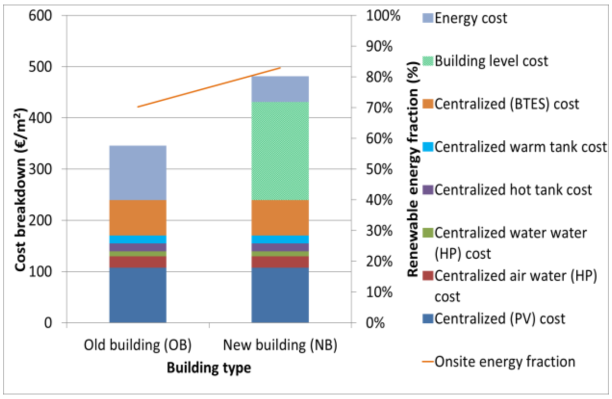

Figure 10: The LCC cost breakdown and onsite energy fraction of Case 2.

Cost and emission comparison between the energy systems

Table 3 shows the emissions, relative emission reduction, LCC and emission reduction cost when either the OB or NB is integrated with the reference city level energy grids (case 0) and centralized renewable energy systems (cases 1 and 2). It is observed in Table 3 that the emissions in case 0 with OB is high compared to the emissions in case 2 with OB. The emissions from the old building can be reduced from 33 kg CO_2/yr in case 0 to 10.2 kg CO_2/yr in case 2. The emissions can be influenced by integration of seasonal storage in Nordic conditions (case 2). Due to the change in the energy system, the investment cost increased and as a result, the emission reduction cost increased to 10.49 €/kg CO_2/yr in case 2. This is the investment cost needed on the energy system. It can be observed that the emissions from the old buildings can be reduced by integrating building with the renewable based energy system and seasonal storage.

It is observed in Table 3 that the emissions from the NB can be reduced if NB is integrated with case 2 instead of case 0. The emissions can be reduced from 14 kg CO_2/yr (case 0) to 5.1 kg CO_2/yr (case 2). Compared to OB building as shown in Table 3, the emissions reduction cost for the NB building is generally high. This is because an additional cost is needed on the centralized energy system for NB, and the emission reduction is lower compared to OB. However as shown in Figure 9 and in Figure 10 (case 2), the purchased energy and the energy cost is less for the NB building compared to the OB building.

Table 3: Relative emissions and emission reduction cost for the old building (OB) and new building (NB) integrated with Case 0, 1 and 2.

Case	Emissions (kg CO_2/yr)	Emission Reduction (kg/ CO_2/ m^2/yr)	Relative reduction in emissions (%)	LCC (€/m^2)	Emission reduction investment cost & [LCC] (€/kg CO_2/yr)
0, (OB)	33	-	-	336	-
1, (OB)	15.2	17.8	54	373	9.8, [21]
2, (OB)	10.2	22.8	69	345	10.49, [15.1]
0, (NB)	14	-	-	350	-
1, (NB)	7.1	6.9	50	425	24.6, [61.6]
2, (NB)	5.1	8.9	63	481	27, [54.3]

When comparing OB and NB (Table 3) integrated with the case 0, the emissions can be reduced by 56%. When comparing OB integrated with case 0 and NB integrated with case 2 in Table 3, the emissions can be reduced by 85%, the corresponding emission reduction cost is 8.59 €/kg CO_2/yr (for centralized renewable energy system) and in terms of life cycle cost it is 17.2 €/kg CO_2/yr. This shows that by integrating renewable based energy system with seasonal storage with the energy efficient buildings in the districts, the emissions can be reduced significanlty to reach EU's emission reduction target of 2050 (European Commisssion, 2019). Moreover the LCC per kg CO_2/yr is 28% lower in case 2 compared to case 1 (for

OB) and 12% lower in case 2 compared to case 1 (for NB). This is due to lower operational or energy cost in case 2 compared to case 1 both for the OB and NB.

Conclusion

Two PV based energy systems are proposed for an apartment building assumed located in Helsinki in this study and they are compared against a reference city-level energy system. The apartment buildings are focused as they make up to 26% of the energy consumption, emits around 1 Mtons CO_2 and covers around 21% of the total floor area.

The cases in the study are arranged as follows:

Case 0: Reference city level energy system.

Case 1: PV with ground source heat pump based centralized energy system (PV+GSHP).

Case 2: PV with air and water source heat pump based centralized energy system integrated with seasonal storage (PV+A2WHP+WWHP+BTES).

The LCC, emissions, purchase electricity and onsite energy fractions are evaluated and compared. The design parameters used are the energy system components and building level design parameters. The main outcomes are:

- Case 2 performed better in terms of the reduction in the purchased electricity, CO_2 emissions and purchased electricity cost compared to the case 1 and case 0.
- Case 2 is able to reduce the emissions from the old building from 33 kg CO_2/yr to 10.2 kg CO_2/yr when case 0 is replaced. The emission reduction cost is 10.49 €/kg CO_2/yr.
- Case 2 is able to reduce the emissions from the new building from 14 kg CO_2/yr to 5.1 kg CO_2/yr when reference city level energy system (case 0) is replaced. The emission reduction cost is 27 €/kg CO_2/yr.
- The emissions from the building can be reduced by 85% when the old building is replaced by new building and the new building is integrated with case 2 instead of case 0.
- The onsite energy fraction varied from 48% to 83% depending on the building type and energy system case.
- The LCC increased by 37% for NB when case 0 is changed to case 2. The LCC increased by 3% for OB when case 0 is changed to case 2.

This study can provide guidelines and path to support the EU's and national emission reduction targets. Case study 1 is currently financed, constructed and marketed in Finland, Sweden and Denmark markets. In Finland, around 6 billion euros were invested on such systems. Case study 2 is a novel concept that is presently being developed as a first pilot or demo case in Finland. It is partly financed by European Union. It is expected that such concepts would gain traction in the cold climatic regions for instance in Sweden, Norway, Finland, Canada etc. as the countries around the world commits to meet the emission reduction targets. Building level energy efficiency is useful in terms of emission reduction. However, the challenge of emissions still exists at the district heating and city level energy systems especially in cold regions. Emissions can be reduced from the district heating networks by investing at the centralized renewable based energy systems and storages as discussed in the study. However, the challenge is to find space and install various storages in the old buildings and districts, where empty spaces are less. It can be installed in the nearby parks, undergrounds and parking lots etc. Future districts planning may need to include these storages in the plans. This may need changes at the policy level and business models. The suggested approach will support better utilization of renewables and energy flexibility by the use of storages. Other technologies such as wind turbines, photovoltaic-thermal hybrid and building shapes can be studied in the future work. Moreover, these systems and communities may act as positive energy districts or virtual power plants in the future infrastructure.

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