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Requirements for renovating residential buildings in the Netherlands towards lower temperature supply from district heating.

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Abstract. In the Netherlands, district heating with a lower temperature supply (<70°C) will play a crucial part in accomplishing the energy transition goals of delivering natural gas-free sustainable heating to dwellings. The existing dwellings often require energy renovations to make them suitable for lower temperature heating. However, choosing renovation strategies that promote the transition to lower temperature district heating while improving energy efficiency and thermal comfort is challenging. This study aims to identify minimum renovation requirements for comfortably heating homes using lower temperature heat from district heating. Identifying minimum renovation strategies to prepare existing dwellings for lower temperature district heating would be vital in addressing the European Renovation Wave's target of improving worst-performing buildings. For the same, the study uses a typical intermediate terraced house built before 1945 as a case study to investigate renovation strategies based on four levels of renovation intervention (no renovation, basic, moderate and deep). The impact of renovations on space heating demand and thermal comfort was tested with medium (70/50°C) and low supply (55/35°C) temperatures against key performance indicators (KPIs) using dynamic simulation. The study found that for the case study dwelling, moderate renovation strategy of upgrading the building envelope insulation by 0.40 W/m^{2}K for opaque parts and 1.5 W/m^{2}K for glazing, improving the airtightness by 0.3h^{-1} and replacing existing radiators with LT radiators can be considered as a no-regret solution for comfortably heating homes with both medium and lower temperature supply from district heating.

1. Introduction

In 2020, the built environment in the Netherlands generated 13% of the total national greenhouse gas emissions, 71% of which came from natural gas used for residential heating [1]. As a result, by 2030, the Dutch government plans to reduce 3.4 Mton of $CO_{2;eq}$ emissions by making 1.5 million households natural gas-free [2]. Collective heating technologies such as district heating (DH) systems with lower supply temperatures (<75˚C) have an essential role in this energy transition by delivering gas-free heating. Supply temperature reduction in the DH network provides opportunities to integrate sustainable heat sources [3,5,9], decrease network heat losses, and to increase distribution efficiency [3–7]. On the building level, lower temperature heating (LTH) improves thermal comfort and indoor air quality [8–11]. Although currently only 6.3% of households are connected to a DH system [12], by 2050, it is estimated that 50% of the heat will be provided by DH systems [13].

Therefore, many residential buildings are expected to have a DH connection with a lower temperature supply in the following years.

The increasing energy efficiency of newly constructed dwellings has made it possible to meet space heating demands with lower supply temperatures close to ambient temperatures [4]. However, the problem arises with existing dwellings with high heating demands due to high heat losses. When the supply temperature is reduced, the heating output of the existing space heating system, such as radiators, also decreases [6,14]. A mismatch between higher heat losses and a reduced capacity of existing radiators results in thermal discomfort for the occupants. Therefore, such dwellings would require a higher temperature (HT) supply from DH to maintain thermal comfort. Thus, limiting the supply temperature reduction that in a DH system can be achieved. Additionally, higher peak loads from existing dwellings would be crucial to dimension future DH systems based on sustainable heating sources [15]. As a result, existing dwellings with poor energy performance must undergo energy renovations before lower supply temperatures can be used to meet heating demands.

Currently, existing houses are renovated solely on the initiative of their owners [16]. However, choosing appropriate renovation strategies to heat homes with lower supply temperatures is challenging. Additionally, compared with other European countries, there is a lack of studies on preparing existing housing stock for lower temperature heating in the Netherlands. Therefore, this study aims to identify minimum renovation requirements to comfortably heat homes with lower supply temperatures from district heating systems. The study developed renovation strategies based on four renovation intervention levels and applied them to a typical intermediate terraced house constructed before 1945 with high heating demands as a case study. Each strategy was evaluated for medium and low-temperature supply using dynamic simulations against key performance indicators (KPIs) related to space heating demand and indoor thermal comfort to determine the minimum renovation requirements. Identifying minimum renovation strategies to make existing dwellings suitable for lower temperature district heating would be central to addressing the European Renovation Wave priorities of improving the worst-performing buildings and decarbonizing the heating systems.

2. Materials and methods

2.1. Case study dwelling

The terraced houses (rijwoningen in Dutch) represent 42% of the total residential stock in the Netherlands [17]. Even though renovated from their original condition, these pre-war dwellings (Figure 1) have an energy label of G [17], representing the high heating demands of this dwelling type. Therefore, such dwellings would require renovations before using lower temperature heating. This study used a case example of an intermediate terraced house constructed in 1938. The selected case is also a part of an ongoing "LT Ready" project within the faculty of Architecture and the Built Environment at TU Delft [18].

Figure 1. Typical terraced house built before 1945. The outline illustrates the intermediate position of the dwelling between adjacent terraced houses. Source[17]

2.2. Renovation intervention level and strategies
Individual dwellings within a neighbourhood have different renovation potentials due to varied building profiles, envelope properties and construction styles. Therefore, different renovation strategies were developed based on four levels of renovation interventions in order to cover several possibilities.

- *No renovation.* Exiting condition of the dwelling with no changes at all.

- *Basic renovation.* This intervention level corresponds to strategies only for increasing the heat output of the space heating system without any changes to the building envelope. Therefore, the existing radiators were changed to LT radiators at this intervention level.

- *Moderate renovation.* The Dutch Building Decree [24] states that partial or moderate interventions represent renovations less than 25% of the envelope surface area. In some studies [15,19,20], this level of intervention is also discussed as light renovations, with selected improvements at the building envelope level such as changing windows, post (cavity) insulation of walls, roof or floor. For this intervention, two distinct strategies were chosen: one with minimum insulation levels, as recommended by the Dutch building decree [21], and energy-saving measures (besparingspakket), according to the study by Agentschap NL on representative dwelling types in the Netherlands [22]. The two strategies were also evaluated with or without changing the existing space heating system.

- *Deep renovation.* This intervention level corresponds to the holistic renovation of a dwelling with integral changes such as replacing an entire existing roof. The Dutch building decree [23] stipulates deep renovations covering changes to more than 25% of the building envelope. Furthermore, literature studies [25–28] show that deep renovations include higher building envelope insulations, improved thermal bridges, airtightness, and ventilation systems. Therefore, insulation levels similar to new constructions as per [23], improved airtightness, space heating and ventilation systems were considered for deep renovation.

The four intervention levels were tested with two lower supply temperature levels: Medium-Temperature supply (MT) and Low-Temperature supply (LT), with a supply/return temperature regime of 70˚C/50˚C and 55˚C/35˚C, respectively. Table 1 summarises the renovation strategies according to the definition of renovation intervention levels.

2.3. Method for assessing renovation strategies
The study performed dynamic simulations using Design builder V7.0 and energy plus software to analyse the impact of renovation strategies under lower temperature supply levels as described in the previous section. A calibrated simulation model was created to represent the actual performance of the case study dwelling. The input parameters used for creating the simulation models and the calibration process are discussed elsewhere [24]. Figure 2 indicates the spatial characteristics of each thermal zone, heating conditions, size and type of the radiators. The existing radiators are located below the windows to counteract the cold draught from the window glazing. The heating was scheduled to operate between 8:00-23:00 with an indoor setpoint of 20˚C and a setback of 18˚C between 23:00 and 8:00. The internal gains due to occupants, lighting and equipment were considered to be 4.8 W/m^2. The study only evaluated the living room because occupants spend most of their time in it. Additionally, the living room spans the width of the house, thus allowing the incorporation of the effect of orientation on solar heat gain. Even though the performance of individual rooms might differ, the living room could provide the indicative performance of the entire dwelling.

The KPIs for evaluating renovation strategies were annual space heating demand and hours too cold (underheated hours). The annual area-weighted space heating demand in kWh/m^2/year corresponds to the energy used by the space heating system to compensate for the heat losses due to transmission and ventilation. The study used the adaptive thermal limit (ATL) method for thermal comfort analysis for calculating the "hours too cold". The ATL method, as described by Peeters et al. [25], considers the adaptive nature of occupants by determining the comfort bands for 90% (10% PPD) and 80% acceptability (20% PPD). These comfort bands are different for activity spaces such as the bedroom, bathroom and living room. Therefore, the study calculated the number of occupied hours in the living room below the 20% PPD lower limit to indicate cold hours.

Table 1. Renovation strategies according to four intervention levels. No renovation level represents the existing condition of the case study dwelling. MD1 and MD2 are moderate renovation strategies, and DP1 and DP2 are deep renovation strategies. MD1 and DP2 derive their insulation and infiltration values from the Dutch Building decree [23], while MD2 derives the same values from [17]. DP1 was developed with the improvement of the MD2 strategy.

Component	No renovation	Basic	Moderate		Deep	
			MD1	MD2	DP1	DP2
Space Heating System	Existing Radiators	LT Radiators	Existing or LT Radiators		Existing or LT Radiators	
External Wall (U-Value in W/m^2K)	1.45	1.45	0.71	0.40	0.40	0.21
Floor (U-Value in W/m^2K)	1.45	1.45	0.38	0.40	0.28	0.27
Roof (U-Value in W/m^2K)	0.58	0.58	0.47	0.40	0.28	0.16
Glazing (U-Value in W/m^2K)	2.40	2.40	1.9	1.5	1.1	1.1
Internal Partition (U-value in W/m^2K)	4.16	4.16	4.16	4.16	0.40	0.21
Infiltration (Air change rate in h^{-1})	0.4	0.4	0.3	0.3	0.2	0.2
Ventilation System	Natural Ventilation				Exhaust ventilation with CO_2 sensors	Balanced mechanical ventilation with heat recovery

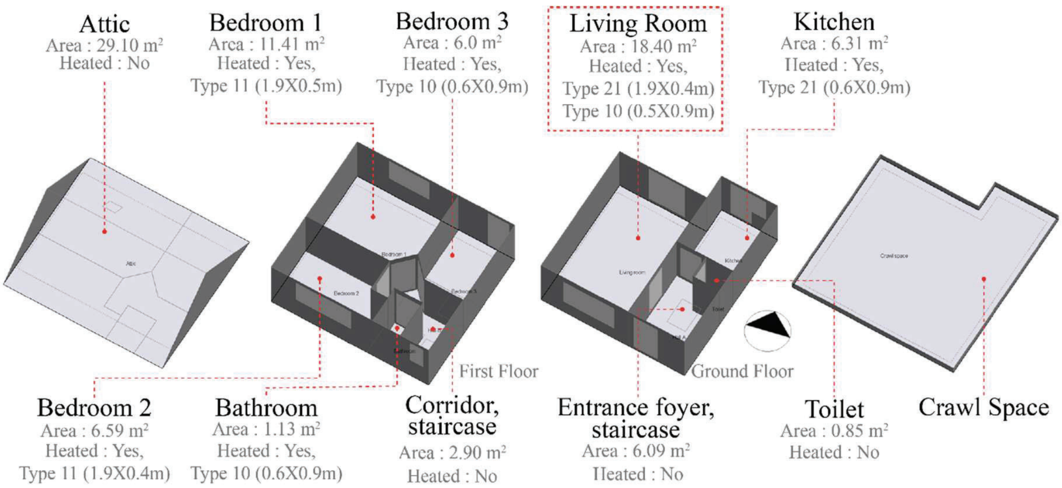

Figure 2. The figure illustrates the surface area, heating condition, the type of radiators, and the radiator's size in meters (length x height) of the dwelling, with only the living room selected for analysis.

The renovation strategies in the presence of lower supply temperature must provide acceptable thermal comfort and reduce the space heating demands compared with the original high-temperature supply. Therefore, the living room was first annually simulated in the existing condition with HT (90/70˚C) supply, using the test reference year specified in NEN5060 [26]. Then, the living room performance concerning the space heating demand and the thermal comfort in HT was used as the benchmark to evaluate different strategies (Table 1) with the two lower supply temperatures to select minimum renovation requirements.

3. Results and Discussions

Table 2 shows annual space heating demand and the occupied cold hours for the existing condition of the living room with HT (90/70˚C) supply. The annual space heating demand for the living room was calculated at 197 kWh/m^2/year. During the year, the living room is occupied for 5840 hours between 8:00-23:00, of which almost 23% (1324 hours) were below the 20% PPD lower limit, indicating "Hours too cold". The minimum renovation requirements must maintain thermal comfort with lower supply temperatures while improving energy efficiency. Hence, the current performance of the living room with HT supply was used as the benchmark for evaluating different renovation strategies. Table 3 shows the annual space heating demand and the number of occupied cold hours below the 20% PPD lower limit for all evaluated strategies.

Table 2. Annual simulation results of the living room under existing conditions with HT supply (90/70˚C). The performance acts as a benchmark for selecting minimum renovation requirements.

	High-Temperature Supply (90/70)	
	Space heating demand [kWh/m^2/year]	Number of occupied cold hours below 20% PPD [hours]
Benchmark performance in the existing condition of the dwelling	197	1324

Table 3. Annual simulation results of the living room with different renovation strategies under MT (70/50˚C) and LT (55/35 ˚C) supply.

Intervention Level	Renovation Strategy	Radiator Type	Medium-Temperature (70/50˚C)		Low-Temperature (55/35˚C)	
			Space heating demand [kWh/m^2/year]	Number of occupied cold hours below 20% PPD [hours]	Space heating demand [kWh/m^2/year]	Number of occupied cold hours below 20% PPD [hours]
No Renovation	Existing	Existing	190	1522	159	2609
Basic	Existing	LT Radiator	204	1306	192	1507
Moderate	MD1	Existing	132	1082	119	1672
		LT Radiator	139	952	133	1072
	MD2	Existing	109	910	99	1305
		LT Radiator	114	833	109	903
Deep	DP1	Existing	64	571	60	640
		LT Radiator	68	548	64	569
	DP2	Existing	38	378	34	395
		LT radiator	40	356	36	358

3.1. Medium-temperature supply (70/50˚C)
Table 3 shows that with no renovation under MT supply, the space heating demand is reduced by 3.5% due to the reduced heating power of the existing radiators under lower supply temperature. As a result, the heating delivered by the radiators is insufficient to compensate for the heat losses resulting in an increase in the number of occupied cold hours by 15% (1522 hours) compared to the benchmark. Therefore, it is suggested that the dwelling require renovations before using the MT supply from district heating.

In the basic intervention level, the renovation strategy only included the replacement of existing radiators with LT radiators. The original dimensions of the radiators (length and height) were kept the same considering the space limitations in the dwelling. From Table 3, it can be observed that the LT radiators have a marginal impact on reducing the number of occupied cold hours compared to the benchmark under MT supply. Since the dwelling has higher heat losses, the LT radiators would require more operational time to heat the space, resulting in a 3.5% increase in the space heating demand. Nevertheless, replacing existing radiators with more efficient ones provides a low-cost and quick solution for using lower temperature heat; they have minimal potential for energy savings. Therefore, it is argued that improving the building envelope for curbing heat losses is far more essential than increasing the heating power of the space heating systems.

For the moderate renovations, strategy MD1 with existing radiators could reduce the space heating demand by 33% and decrease the number of occupied cold hours by 18%. In contrast, strategy MD2 with existing radiators could reduce the space heating demand and number of occupied cold hours by 45% and 31%, respectively. Additionally, when coupled with LT radiators, the two strategies MD1 and MD2 could further reduce the number of occupied cold hours by 28% and 37%, respectively, with a slight increase in the space heating demand due to higher heating power.

Deep renovation strategies with holistic renovations of the building envelope, heating and ventilation systems further reduce the space heating demand and number of occupied cold hours. For example, with strategy DP1, space heating demand and the number of occupied cold hours were reduced by 68% and 57%, respectively. On the other hand, with DP2, space heating demand could be reduced by 81% with a 71% reduction in the number of occupied cold hours compared to the benchmarks. While the existing radiators provide enough heating power to compensate for the heat losses with deep renovation, in practice, they may also be changed to LT radiators while applying deep renovations, which can further reduce the number of cold hours (Table 3). However, with deep renovations, there might be a risk of summer overheating that would require other strategies for preventing and controlling heat gain during the summer period. Therefore, further analysis of summer overheating is suggested for a comprehensive evaluation of renovation strategies for LTH.

3.2. Low-temperature supply (55/35˚C)
The highest discomfort is achieved when the supply temperature is further reduced to LT (Table 3). With no renovations, the number of occupied cold hours is almost double the benchmark of 1324 hours. Even with the basic renovations, the number of occupied cold hours does not go below the benchmark performance. With the moderate renovation, MD1 could reduce the space heating demand by 40%, although only when it is coupled with LT radiators were the number of occupied cold hours reduced by 19%. The strategy MD2 could reduce the space heating demand by 50%, with only a marginal reduction (1%) in the number of occupied cold hours. When combined with LT radiators, the MD2 strategy could reduce the number of occupied cold hours by 32%. Deep renovation strategies can further reduce the space heating demand below 60 kWh/m^2/year with a 50-70% reduction in the number of occupied cold hours.

3.3. Recommendations for minimum renovation requirements.
To prepare a house for a lower temperature supply, renovation strategies must improve thermal comfort compared to the existing case with HT supply, along with improvements in energy efficiency. Table 3 shows the performance of the renovation strategies under MT and LT supply.

Among the various strategies, moderate renovation strategies (MD1 & MD2) with or without radiator replacement can comfortably heat a home using MT supply. However, the MD2 strategy with LT radiators enables the dwelling to be comfortably heated even with LT supply while reducing space heating demand. On the other hand, deep renovations achieved the most significant reductions in space heating demand and the number of occupied cold hours, although there is a constant risk of summer overheating with deep renovations. Furthermore, deep renovations coupled with additional systems to prevent legionella growth in domestic hot water systems can result in expensive solutions for property owners. As a result, the MD2 strategy, with the LT radiators, can be considered a no-regret solution for existing dwellings for transitioning to lower supply temperatures from district heating. In other words, the solution can be considered minimum renovation requirements for the selected case study for using both MT and LT supply temperature levels.

4. Conclusions

The study's primary objective was to determine minimum renovation requirements to prepare existing dwellings in the Netherlands to be comfortably heated with a lower temperature supply from district heating. The study evaluated four levels of renovation interventions with subsequent strategies in the living room of a typical terraced house built before 1945 as a case study using dynamic simulation. The main findings can be summarised in the following points:

- The basic renovation strategy of increasing the heat output of the existing radiator systems cannot alone prepare the case study dwelling to be heated with a lower temperature supply from district heating.
- The moderate renovation strategy that upgrades the building envelope insulation by 0.40 W/m^2K (opaque part) and 1.5 W/m^2K (glazing), infiltration by $0.3h^{-1}$ and with LT radiators is a no-regret option for using both MT (70/50˚C) and LT(55/35˚C) supply.
- This strategy with MT supply could reduce the space heating demand and the number of occupied cold hours by 42% and 37%, respectively. While using LT supply, the same strategy can reduce the space heating demand by 45% and the number of occupied cold hours by 32%.
- Deep renovation strategies can further improve energy efficiency and thermal comfort, although the solutions might increase the risk of overheating, which must be included in future analyses.

Since this study was limited to one dwelling type and construction year, further studies are required for other dwelling types existing within a neighbourhood. Furthermore, indicators for selecting renovation requirements must be extended toward economic and environmental aspects.

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