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Energy Savings Across EU Domestic Building Stock by Optimizing Hydraulic Distribution in Domestic Space Heating Systems

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Energy savings across EU domestic building stock by optimizing hydraulic distribution in domestic space heating systems

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ABSTRACT

The objective of this work is to quantify the resultant savings across the EU from the optimization of existing system components in domestic space heating distribution systems to maintain comfort levels. Heat energy savings are shown to range from 1% to 19% depending on dwelling type, age, location and initial specific heat energy consumption. Total potential savings across the sector amount 22.6 Mtoe, a reduction of 7.3%; 53% of these from a reduction in pumping power required by heating distribution systems and 47% of these from a reduction in the heat energy consumed by heating systems. The carbon abatement potential is estimated to be 496 million tonnes of CO_2 equivalent. Regulatory changes to the domestic replacement and maintenance industry are required for these low-cost, high impact and highly applicable energy saving measures to be adopted more extensively.

1. Introduction

Building energy consumption represented 41% (up from 37% in 1990) of total final European Union (EU) energy consumption in 2010, 27% of which was consumed in residential buildings and 14% in non-residential buildings. As can be seen in Fig. 1.0.1, buildings are the second largest end-use, followed by transport, and industry. Dwellings constitute 76% of the total building floor area in the EU, 65% of which, as shown in Fig. 1.0.2, is attributed to houses [1]. Annual unit consumption per m^2 for residential buildings in European Union (EU) is around 200 kWh/m^2 [1]. In the 27 EU member states in 2009 (EU 27), space heating consumed 68% of energy used in the residential sector, accounting for 210 million tonnes of oil equivalent (Mtoe) or 244.23 TWh [2]

Despite the construction and occupations of new energy-efficient buildings, the thermal characteristics of an existing building stock will remain dominant for a number of years simply because newer buildings are always a smaller part of the total stock. The duration of dominance of pre-existing houses depends on the rate, floor area and specification of new dwelling construction. In the United Kingdom for example it has been estimated that around 75% of dwellings that will exist in 2050 have already been constructed [3]. To achieve energy savings, energy refurbishment of existing houses thus needs to take place [4–6]. Energy efficiency interventions can either be ‘passive’, to improve the building envelope and/or ‘active’ to improve the building services [5,7]. The capital costs of retrofitting passive fabric improvement measures such as external insulation or replacing the active heat generation plant are unaffordable to many end-users [4,8–10]. A low initial cost is incurred upgrading particular aspects of existing active systems such as the installation of thermostatic radiator valves and/or a high efficiency heating circulation pump in the dwelling heating system.

Domestic space heating has been dominated by fossil fuels, efficiency improvement in space heating will thus reduce greenhouse gas emissions [4,7,11–13]. Heating system efficiency depends upon the thermal performance of the building envelope, occupancy [14] and climate, as well as the performance the system’s component parts [15–20]. Whilst, in most heating systems well-functioning energy efficient components are installed these components may not be (i) optimally adjusted to the particular variations in energy load encountered and (ii) set-up to optimally communicate effectively with one another [9,15,18,20–22]. Seemingly innocuous inaccurate settings of individual components can lead to significant over-consumption of energy [9,20]. Energy savings can thus be realised through communication that provides optimal cooperation between existing boilers, pumps, controllers and thermostats in a typical domestic space heating system such as that shown in Fig. 1.0.3.

The objective of this work is to quantify the resultant savings across the EU from the low-cost optimization of existing system

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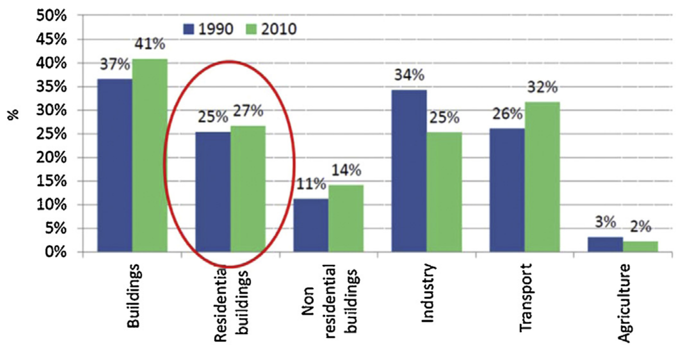

Fig. 1. Share of buildings in final energy consumption in the EU [2].

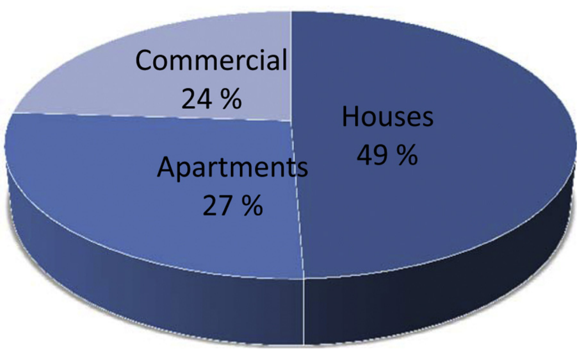

Fig. 2. Distribution of building floor area in the EU [2].

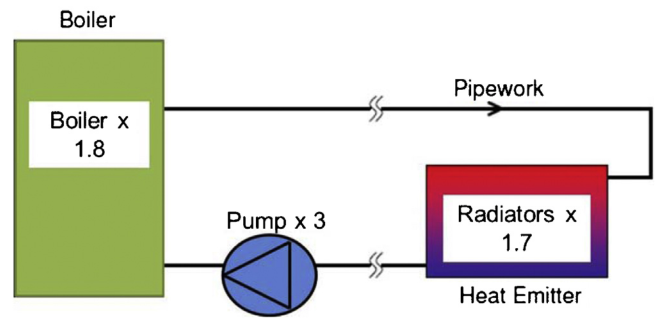

Fig. 4. Typical component oversizing [20].

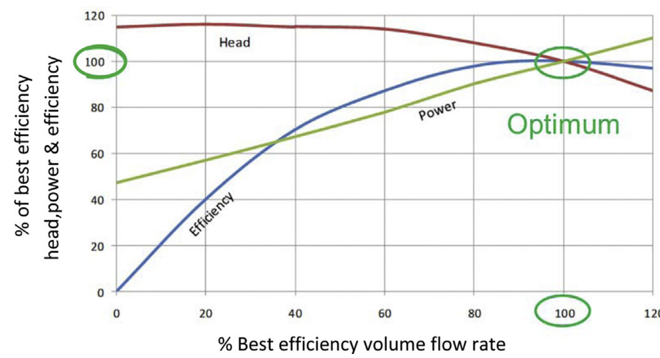

Fig. 5. Optimum operating point of a pump [31].

components in domestic space heating distribution systems to maintain comfort levels.

1.1. Typical European residential space heating systems

The majority of heating systems combust a fossil fuel to generate heat and use electrical energy to pump heat via a hydraulic distribution system to radiators [15,17,23]. Energy efficiency gains from heat distribution systems are not always optimal with even the most progressive energy standards failing to regulate to ensure the energy saving potential of the system is fulfilled [4,6,9,12,15,24–26]. A tendency to oversize heating plant leads up to 50% higher energy consumption, particularly at part load operation [15,16,18,27,28]. A study of 92 dwellings in Northern Germany between 2002 and 2005 found that, on average and as illustrated in Fig. 2.0.1, boilers were oversized to the peak heat load by a ratio of 1.8, pump design was typically 3 times bigger than was required, and radiators were also typically oversized by a ratio of 1.7 [20]. A study of 56 dwellings in Belgium found boilers had been typically oversized by a ratio of 3 [15].

Heating circulation pumps account for 2–3% of overall EU energy consumption in dwellings, resulting in CO_2 emissions of more than 20 million tonnes in 2006 [29,30]. The efficiency of the heating circulation pump varies with its;

(i) size (flow, diameter, power)
(ii) the viscosity and temperature of fluid conveyed, and
(iii) the closeness of the pump's actual operating point to its optimal operating point.

As illustrated in Fig. 2.0.2, excessive flow rates incur unnecessary power consumption; for example doubling the flow rate results in eight times the electrical power consumption.

Hydraulic adjustment of water distribution in a pipe network is achieved by the introduction of pre-settable thermostatic radiator valves or adjustable lock shield valves as hydraulic resistors that balance flow rates. Pre-settable thermostatic radiator valves are

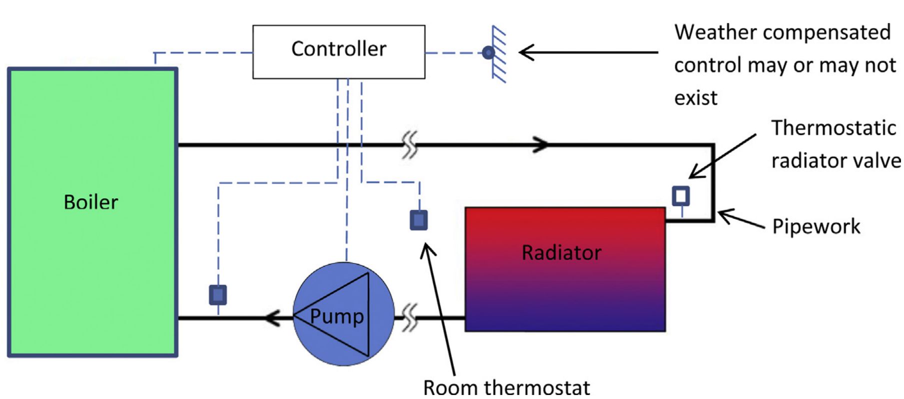

Fig. 3. Simplified typical domestic heating system.

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Table 1
Optimization interventions applied in the OPTIMUS study [40].

Controls	Commissioning of any pre-existing control devices for example weather compensated flow controller and adjusting heat operating times.
Hydraulic balancing	Hydraulic adjustment of water flow rates in the pipe network to design/optimal flow rates via pre-settable thermostatic radiator valves.
Pumping power	Installation of high efficiency variable speed drive pump or, at a minimum, optimising the setting of the existing fixed speed pump. Removal of bypass line and valve associated with typical fixed speed pump when high efficiency variable speed drive pump installed.
Insulation	Insulating the pipe network.

available commercially [32,33] that allow fine tuning of the heating water to optimal design flow rates.

An absence of hydraulic balancing, as shown in Fig. 2.0.3, means that;

(i) the radiator closest to the pump receives an oversupply of heating water and a greater than design heat output (red),
(ii) while radiators remote from the pump are undersupplied resulting in a lower heat output than designed (blue).

To overcome the lack of hydraulic balancing within the system either (i) the speed of the pump is increased or (ii) a larger pump can be installed, as illustrated in Fig. 2.0.4 [20,29,34,35].

The 'remedy' of oversizing of the pump is often unbeknown to the end-user who unwittingly pays the ensuing electricity costs, constituting between 5% and 10% of a typical the domestic electricity bill in 2006 [29]. The alternative remedy of increasing the speed of the pump can lead [34,36];

(i) An unacceptable noise nuisance particularly where the pump head happens to be very large.
(ii) Ineffective installed thermostatic radiator valves as their design tolerances have been exceeded.

The maximum reduction in the pump's electrical power consumption is achieved by balancing the flow rates within the distribution system via finely tuned presettable thermostatic radiator valves, as shown in Fig. 2.0.5.

Correct hydraulic balancing has been found to be present in less than 10% of heating systems with less than half of systems having pre-settable thermostatic radiator valves installed [20]. As shown in Fig. 2.0.6, a fixed speed pump used in European domestic heating systems typically has a power input in the range of 80–100 W [34]. For such systems, when the hydraulic balance is correct a 35 W fixed speed pump would be sufficient and either;

(i) The installation of a high efficiency variable speed drive pump or
(ii) optimizing the setting of the existing fixed speed pump curve

offers significant energy savings [34]. Athough the savings will vary from system to system, both options are viable economically under common operating conditions [37]. Energy savings in domestic heating systems of 23 TWh could be achieved across the EU by 2020 if the existing stock of fixed speed pumps were replaced with the high efficiency variable speed type circulators with an 'Ecodesign Directive' energy efficiency index in the range of 0.20–0.30 [38,39].

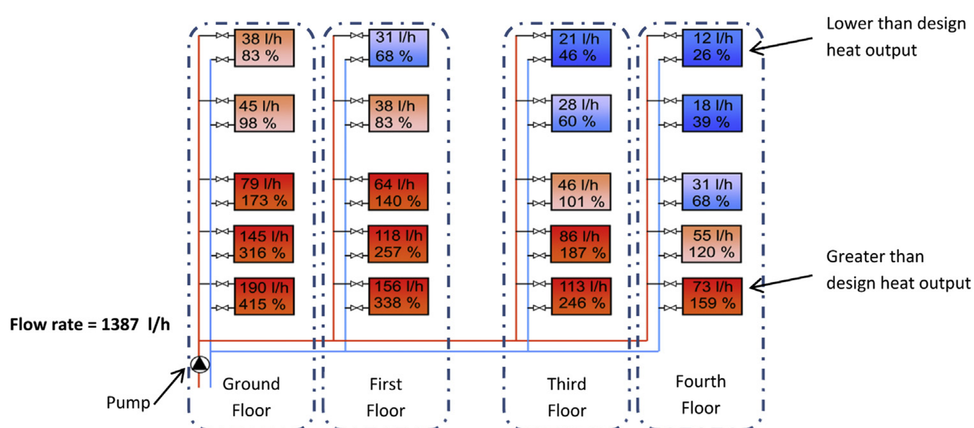

Fig. 6. Typical 'unbalanced' heating distribution system.

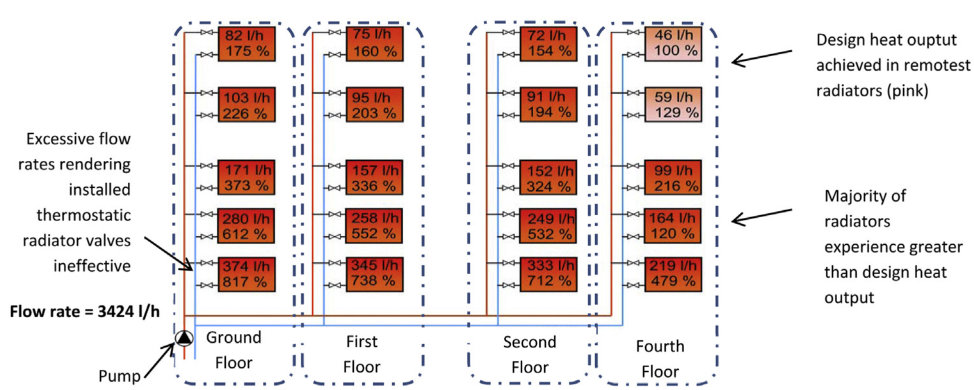

Fig. 7. Typical 'remedy' applied to 'unbalanced' heat distribution system.

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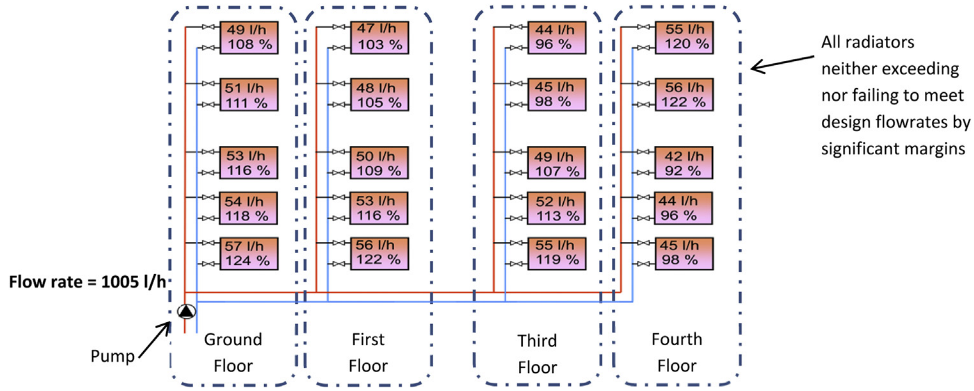
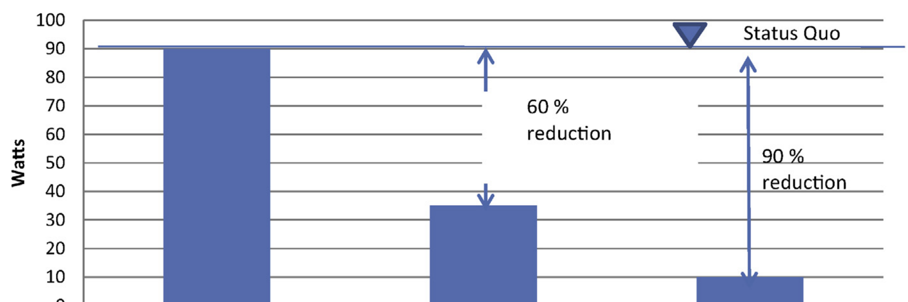


Fig. 8. Flow rates in a heating distribution system balanced by finely tuned thermostatic radiator valves.



	Typical Existing Oversized Circulator (Typical non-optimized system)	Typical existing circulator (Optimized System)	High efficiency VSD circulator (Optimized System)
Series1	90	35	10

Fig. 9. Comparison of the input power of various heating pumps in different systems [34].

Under the OPTIMUS study [40], data for 75 dwellings with installed heat and electricity meters, as depicted in Fig. 2.0.7 was analysed after the 2002/2003 heating season, 19 single-family dwellings and 11 multi-family/apartment dwellings with relatively high heat consumption comprising were selected for some or all of the optimization interventions described in Table 2.0.1.

The heat energy consumption characteristics of 45 'non-optimized' and 30 'optimized' systems were monitored over the 2003/2004 and the 2004/2005 heating season, designated heating season A and B. The benefit of heating system optimization is apparent from Fig. 2.0.8 with optimized dwellings reporting a reduced, weather adjusted energy consumption of 8 kWh/m^2/yr between the season A and B. As shown in Fig. 2.0.8, the study notes the difference of "less than 1 kWh/m^2/yr" in the 45 non-optimized control buildings between seasons A and B and thus gives an adjusted reduction in energy consumption of 7 kWh/m^2/yr through 'optimization' [19]. The adjusted Fig. of 7 kWh/m^2/yr is used in subsequent analysis.

As shown in Fig. 2.0.9, virtually no savings were apparent through the optimization process in the oldest dwellings constructed before the installation of thermal insulation was made mandatory by building regulations in 1977. This is evidence of heating system optimization enabling higher internal temperatures to be provided in poorly insulated dwellings [15,42]; little or no reduction in energy consumption then ensues. In some of the older dwellings surveyed, optimization measures resulted in a slight increase in heat energy consumption due to a now homogeneous heat distribution being achieved in all rooms [20,43]. Optimization interventions, therefore, at a minimum, increase comfort as more uniform heating is provided by the radiators. In newer dwellings, which have lower heat consumption due to better energetic standards, greater energy savings are realised through heating system optimization.

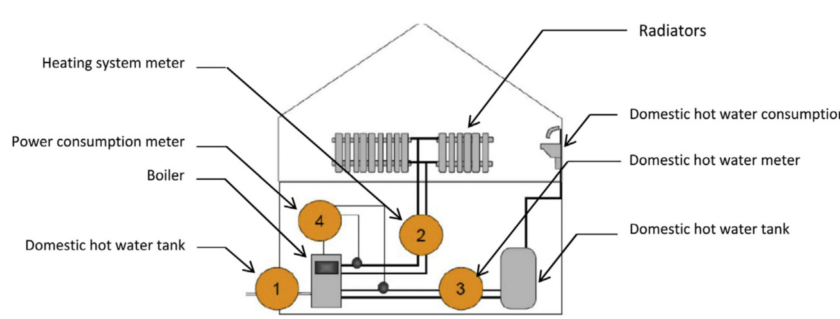


Fig. 10. Location of energy meters in relation to heating system components in the OPTIMUS study[41].

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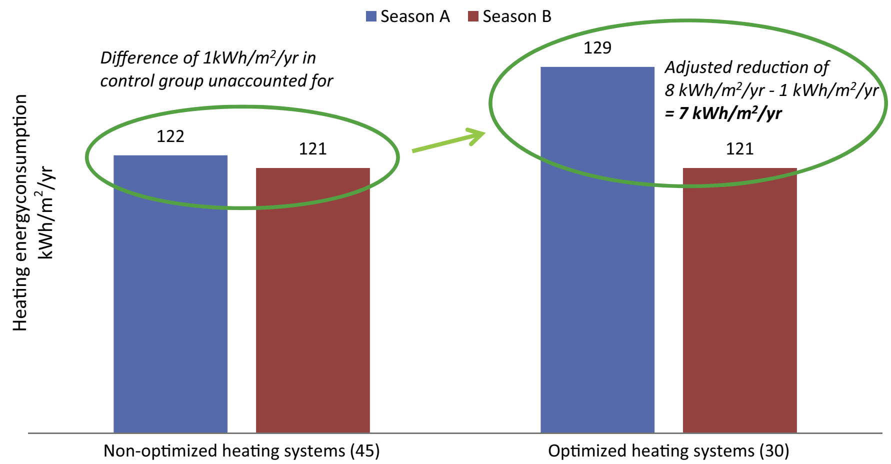

Fig. 11. Adjusted heating consumption between the optimized and non-optimized system states at system level [19].

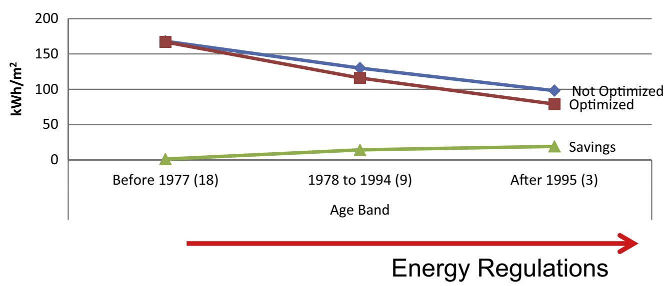

Fig. 12. Adjusted heat energy consumption pre and post optimzation by dwelling type and construction period.

The electrical energy required to pump heat to the emitters was monitored in 27 dwellings between season A and B [40]. As shown in Fig. 2.0.10, an averaged reduction of 0.38 kWh/m^2/yr between the non-optimized and optimized system states was reported. The difference of the 0.08 kWh/m^2/yr reported in the 38 non-optimized control dwellings between season A and B gives an adjusted reduction in energy consumption of 0.3 kWh/m^2/yr through the optimization interventions. The adjusted figure of 0.3 kWh/m^2/yr is used in subsequent analysis irrespective of dwelling age [19].

1.2. Methodology

To quantify the resultant savings across the EU from the low-cost optimization of existing system components in domestic space heating distribution systems to maintain comfort levels the potential energy savings indicated by the OPTIMUS (Wolff 2006) study were extrapolated to the full 27 states of the EU by;

(i) dwelling age
(ii) initial specific energy consumption of the dwelling (kWh/m^2/yr)
(iii) dwelling type (single-family or multi-family), and
(iv) electrical or heat energy savings.

The methodology, summarised in Fig. 3.0.1, assumed that;

(a) the results established for a moderate climate also could be applied to warm and cold climates
(b) multiple sources of data for the housing analysis has common definitions of building type.

Base specific heat energy consumption figures (kWh/m^2/yr) were established under a ‘business-as-usual’ scenario [24] that assumes;

(i) compliance with refurbishment measures and implementation of new building codes varies between countries
(ii) refurbishment of the building stock is relatively slow and
(iii) not every refurbishment is done as it ideally should be.

The assumptions tend to conservative results. The adjusted potential heat energy savings as shown in Fig. 2.0.8 were applied to these base figures to form Table 3.0.1. In Table 3.0.1, the energy

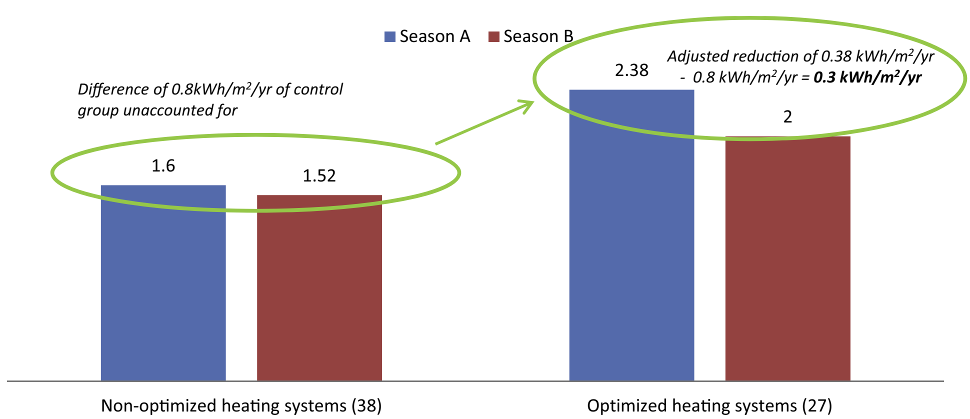

Fig. 13. Adjusted electrical consumption between the optimized and non-optimized system states [19].

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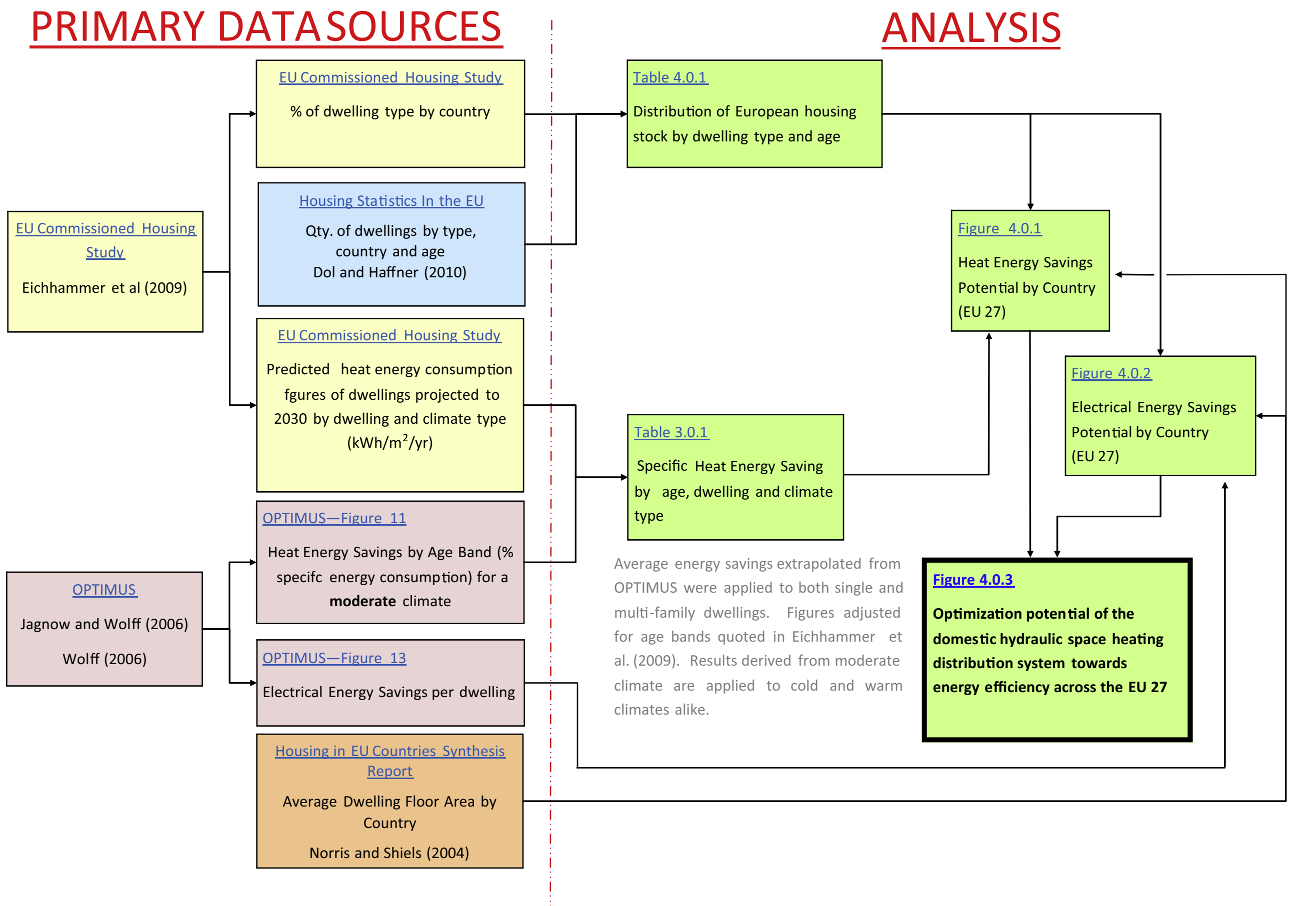

Fig. 14. Summary of primary data sources and their analysis.

savings potential of heating system optimization is shown to range from 1% to 19% depending on dwelling type, age, location and initial specific energy consumption.

Domestic heat energy consumption figures under a high-policy scenario [24] that assumes "full compliance with the respective standards" resulting in lower specific heat consumption figures than that predicted under the business-as-usual scenario. As shown in Table 3.0.2, if the adjusted potential heat energy savings shown in Fig. 2.0.9 are applied to these lower base figures, resultant savings though optimization and form a greater percentage of the whole, ranging from 1% to 30%, again depending on dwelling type, age, location and initial specific energy consumption.

In order to extrapolate the potential energy savings indicated by OPTIMUS study to the full 27 states of the EU, European Dwelling stock was categorised by (i) the type of dwelling, (ii) its location and (iii) the age of dwelling. Quantity of European dwellings by dwelling type and location were established from EU housing statistics [44]. As shown in Fig. 3.0.1 and because housing statistics for some countries was not always categorised by 'dwelling type' (single-family or multi-family), data from Eichhammer et al. (2009) [24] was employed to apply typical percentage breakdowns of dwelling type by country. Subsequently, the cumulative housing data was categorised into relevant comparative age bands.

Table 2
Predicted heat energy savings by dwelling type, location and age for a 'business-as-usual' scenario.

Average specific energy consumption of a single-family building (kWh/m^2)							
Building standard	Age band	Cold		Moderate		Warm	
		Pre.Opt	Saving (%)	Pre.Opt	Saving (%)	Pre.Opt	Saving (%)
Old without refurbishment	Before 1977	197	1	269	0	272	0
Old already refurbished	Before 1977	158	1	225	0	212	0
Intermediate	1978–1995	165	**8**	219	**6**	188	**7**
New	1995–Present	158	**12**	192	**10**	170	**11**
Average specific energy consumption of a multi-family building (kWh/m^2)							
Old without refurbishment	Before 1977	142	1	177	1	168	1
Old already refurbished	Before 1977	122	1	150	1	126	1
Intermediate	1978-1995	117	**12**	125	**11**	112	**13**
New	1995-Present	113	**17**	118	**16**	102	**19**

Note: Table for discussion purposes only. The same average energy saving figures were extrapolated from Jagnow and Wolff (2006) [19] and applied to both single and
Q5 multi-family dwellings. Figure have been adjusted for age bands quoted in Eichhammer et al. (2009) [24] for the autonomous progress scenario (Tables 7–9). Results derived
Q6 from moderate climate are applied to cold and warm climate for reference purposes only.

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Table 3
Predicted heat energy savings by dwelling type, location and age for a high policy scenario.

Average specific energy consumption of a single-family building (kWh/m²)							
Building Standard	Age Band	Cold		Moderate		Warm	
		Pre.Opt	Saving (%)	Pre.Opt	Saving (%)	Pre.Opt	Saving (%)
Old without refurbishment	Before 1977	197	1	269	0	272	0
Old already refurbished	Before 1977	141	1	197	1	173	1
Intermediate	1978-1995	134	10	179	8	133	11
New	1995-Present	122	16	137	14	107	18
Average specific energy consumption of a multi-family building (kWh/m²)							
Old without refurbishment	Before 1977	142	1	177	1	168	1
Old already refurbished	Before 1977	102	1	130	1	98	1
Intermediate	1978-1995	93	15	86	16	75	19
New	1995-Present	86	22	74	26	63	30

Note: Table for discussion purposes only. The same average energy saving figures were extrapolated from Jagnow and Wolff (2006) [19] and applied to both single and multi-family dwellings. Figures have been adjusted for age bands quoted in Eichhammer et al. (2009) [24] for the high policy intensity scenario (Tables 7–6). Results derived from moderate climate are applied to cold and warm climate for reference purposes only.

1.3. Results

The results of the housing analysis are presented in Table 4.0.1 which forms the basis of the EU housing data employed in the analysis. As illustrated in Fig. 3.0.1, average floor areas for EU dwellings were combined with

(i) EU housing data (Table 4.0.1) and savings indicated in Table 3.0.1 to calculate the potential heat energy savings by country and
(ii) the electrical savings found in Fig. 2.1.10, to calculate the potential electrical energy savings by country [45].

The heat energy saving potential resulting are presented in Figs. 4.0.1 and 4.0.2. The total heat energy savings potential of heating system optimization across the EU 27 is in the region 10.5 Mtoe or 122TWh, which amounts to circa 228 million tonnes of CO2 equivalent assuming 0.19 kg of CO2 per is produced per kWh of heat energy production [46]. The analysis indicates a potential to reduce the heat energy consumption of European dwellings by an average of 5%, equating to an overall reduction of 3.4% across the sector. Shown in Fig. 4.0.1, are the savings by country.

The potential savings resulting from reduction in pump power required by the heat distribution system amount to 5.8 TWh, which, when a primary energy conversion factor of 2.6 is applied [47]; results in a primary energy saving of 15.08 TWh or 12.09 Mtoe. This equates to circa 268 million tonnes of CO2 equivalent assuming 0.19 kg of CO2 per is produced per kWh of heat energy production [46]. The resultant saving indicates a potential reduction in primary electrical energy across the sector of 3.9%.

Total potential savings across the sector amount 22.6 Mtoe (−7.3% across the sector), 53% from savings in electrical energy and

Table 4
Distribution of European housing stock by dwelling type & age (*1000).

		Number of dwellings (thousands)					
		Multi-family			Single-family		
		<1980	1981–1995	1996–2009	<1980	1981–1995	1996–2009
Country	Austria	1235	339	280	1162	319	263
	Belgium	1133	297	na[a]	2861	752	na[a]
	Bulgaria	na[a]	na[a]	na[a]	na[a]	na[a]	na[a]
	Cyprus	56	51	17	75	67	22
	Czech Republic	1601	434	161	1190	322	120
	Denmark	857	128	102	1256	188	150
	Estonia	443	122	25	46	13	3
	Finland	999	402	258	678	273	175
	France	9945	1971	1726	12,846	2546	2229
	Germany	20,776	4977	2209	8400	2012	893
	Greece	2072	819	224	1563	618	169
	Hungary	1254	384	126	1805	552	182
	Ireland	62	30	38	708	342	440
	Italy	9695	6579	4094	3285	2229	1387
	Latvia	509	176	59	204	71	24
	Lithuania	787	163	31	262	54	10
	Luxemburg	60	5	3	106	9	5
	Malta	15	7	3	68	32	14
	Netherlands	1332	441	286	3265	1080	702
	Poland	6026	2216	568	2968	1091	280
	Portugal	1534	765	469	1534	765	469
	Romania	2804	676	185	3568	861	236
	Slovakia	651	217	33	625	209	32
	Slovenia	300	79	28	288	76	27
	Spain	12,081	3665	1341	5685	1725	631
	Sweden	1981	299	181	1644	248	150
	United Kingdom	3572	893	na[a]	15,228	3807	na[a]
	Total	81,780	26,135	12,447	71,320	20,261	8613

Q7 [a] Data not available [44].

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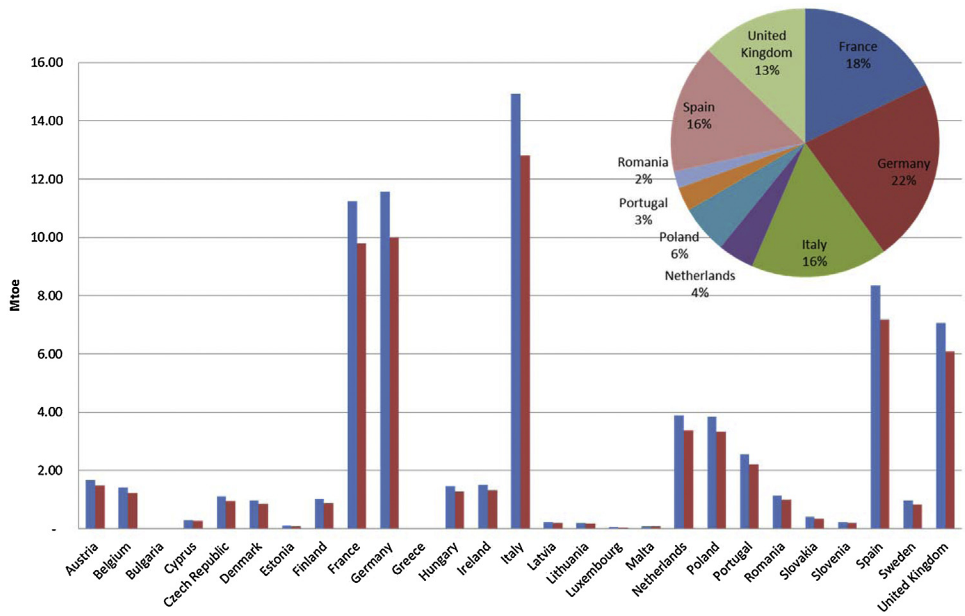

Fig. 15. Heat energy consumption of optimised vs non-optimized heating systems by country.

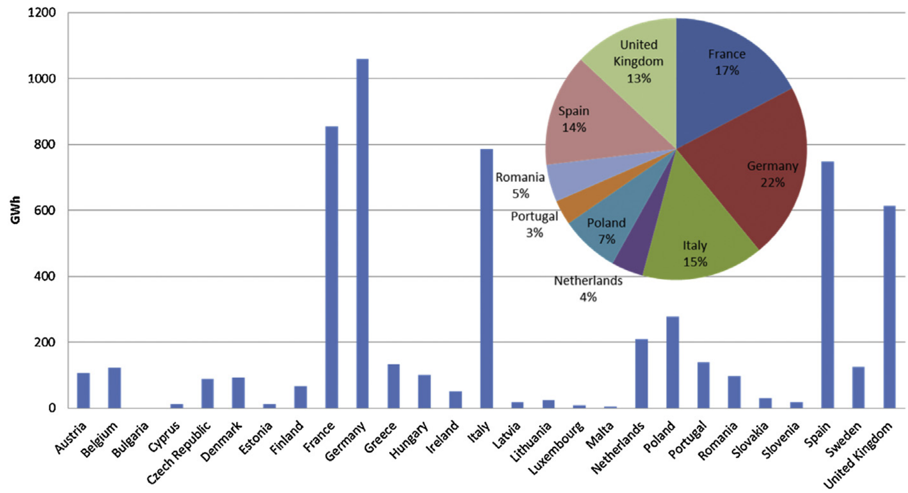

Fig. 16. Potential savings in electrical energy consumption of the optimized heating system by country (secondary energy).

47% from heat energy consumption. The carbon abatement potential is estimated to be 496 million tonnes of CO2 equivalent. As shown in Fig. 4.0.3, the results are significant due to the relative energy consumption of the sector being so large (68%). As shown in Fig. 4.0.4, heat energy saving potential across the EU 27 is limited by the fact that 67% of the European dwelling stock was constructed prior to 1980 where no savings are apparent from the optimization process.

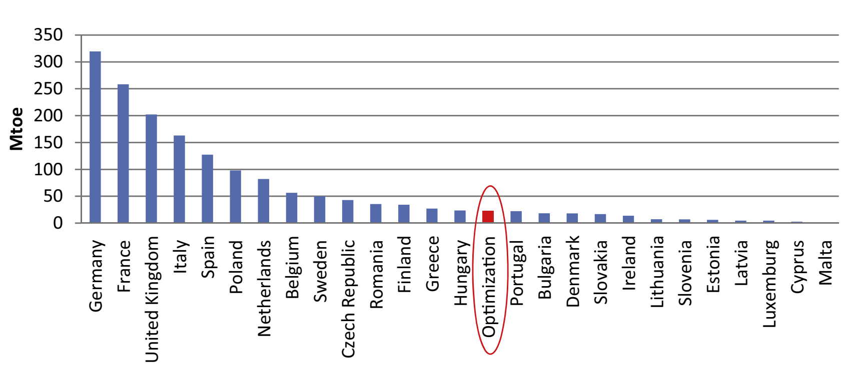

Fig. 17. Savings from optimization of the domestic hydraulic space heating distribution system towards energy efficiency ranked against gross inland consumption figures for the EU27 in 2012 [48].

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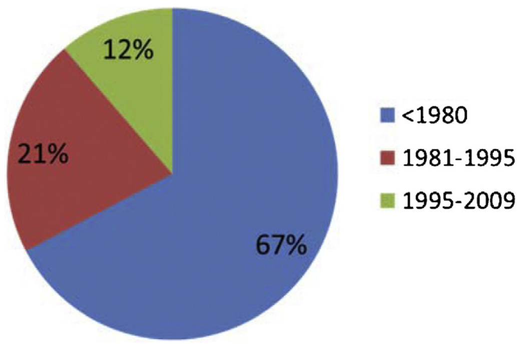

Fig. 18. Distribution of European Dwelling by Age Band [45].

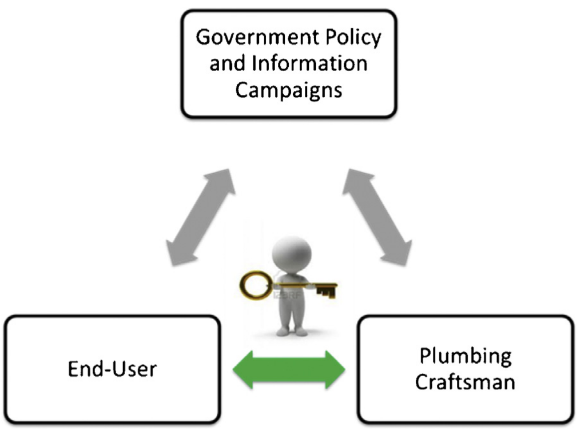

Fig. 19. Key stakeholders of the domestic plumbing and heating sector.

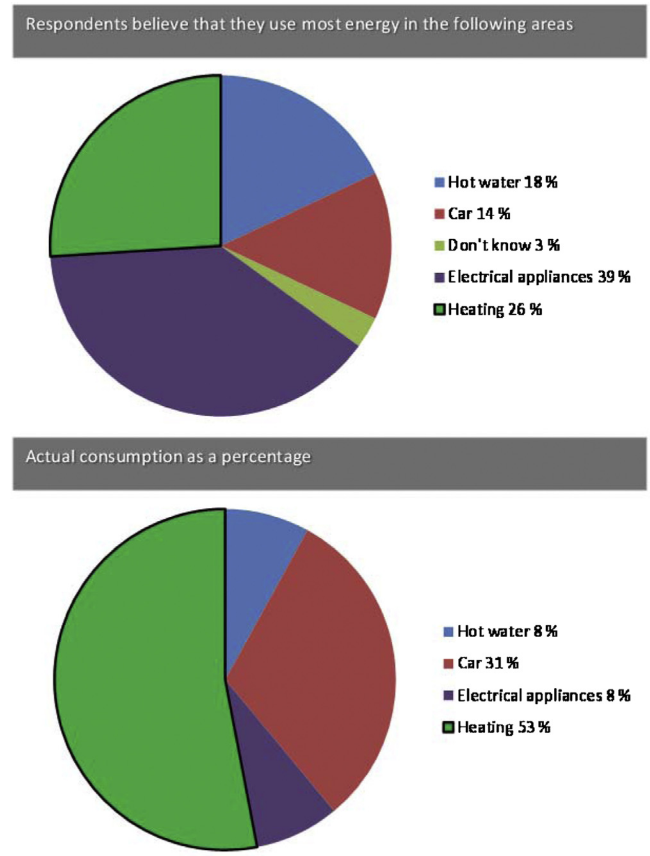

Fig. 20. End-user responses to a German domestic energy survey [52].

1.4. Barriers to implementation

OPTIMUS [20] reported relatively low investment costs ranging between €2 and €7 per square meter of dwelling floor area for the optimization measures applied to heating distribution systems located in Northern Germany outlaid in the years 2003 and 2004. The range in investment costs was principally dependent on whether (i) a new variable speed drive pump was installed and (ii) the number of new thermostatic radiator valves required. Average investment costs related to the heated areas for dwellings located in Northern German were reported to be 3.65 €/m^2 (Jagnow and Wolff 2006 [19]). This is equivalent to an average cost of €438 for a 120 m^2 single family dwelling and €5318 for a 1457 m^2 multi-family or apartment building. It is problematic to summarize the investment cost of optimization measures across EU countries as investment costs vary in individual countries. Even so optimization measures are low-cost, high impact and highly applicable energy saving measures; it is therefore puzzling that they are not adopted as evidenced by the low efficiencies of domestic heating systems being below expectation. To resolve this puzzle requires consideration of the market structure of the plumbing and heating sector. The key stakeholders in the sector are summarized in Fig. 5.0.1.

When building or retrofitting a house, the design and specification of the heating installation is often considered last as it does not proportionally increase the value of a property [49]. The domestic heating market is thus supply-driven, as the demand for operational energy efficiencies by the end-user is often missing [20,30]. As shown in Fig. 5.0.2, end-users have been found to be generally unaware of the energy saving potential of their heating system, being unconcerned about the system performance so long as it realises the desired indoor temperature [4,15,29,50,51]. Good comparative information about user settings and their effects has not been available, for example, the majority of occupants do not know how to correctly operate installed thermostatic radiator valves [9,10,15].

The determining factor in the uptake of energy efficiency upgrades in the plumbing and heating sector is the relationship between the end-user and the craftsman (or expert). Since the end-user does not have to submit the heating system to an official inspection, it is often left to the craftsman to take the initiative in promoting and adopting energy efficiency measures for the system [52]. In upgrade works the end-user needs to trust an installer's competence and the quality of the advice given [50–53]. The quality of advice can be undermined by inherent vested commercial interests in the advice provided. It is therefore important, that information campaigns ensure end-users receive the heightened expectation messages [51]. However, there is no regular European information policy for energy efficiency in residential space heating [6,20]. Individual installers can be trained and encouraged, supported and/or mandated to do the best possible energy efficiency upgrades of the heating systems. For instance, when carrying out repairs or modifications on a system, there could be regulations enacted to support the installer to optimize systems [20,30,54].

That EU "member states are largely underestimating the importance of energy services and the market for companies that deliver them" [12] illustrates the regulatory focus on utility and energy service companies. Very few regulatory or policy perspectives on domestic energy in the EU focus on installers as a key stakeholder in the energy services market. This is because the sector has challenging characteristics that render interventions difficult, for example in Ireland the typical plumbing craftsman in the residential market works alone or with one other and, not being a member of a national body, does not engage with any formal continuous professional development [55]. Design innovation and the

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complexity of the heating systems is increasing, there is therefore a requirement for continual professional development to enable the plumbing craftsman to have (i) a system level approach and (ii) a high level of responsibility for the overall efficiency of the system [20,25,52,56,57]. Pedagogic approaches need to be in place to produce apprentices that have good technical and communication skills to allow them to function effectively in the workplace [56,58,59].

1.5. Conclusions

Optimization of existing space heating hydraulic distribution systems has the potential to contribute a saving of 22.6 Mtoe (−7.3% across the sector) with an associated carbon abatement potential estimated at 496 Million Tonnes of CO_2 equivalent, critically without significant investment costs to the end-user.

Plumbing craftsmen are key facilitators in realising the energy savings potential of the residential heating and plumbing sector. Their education needs to enable them to diagnose correctly system malfunctions and promote best practice optimization measures to end-users effectively [50–53,56].

Optimization of existing space heating distribution systems is low-cost and high impact. In the EU member states need to introduce domestic policy measures to address the poor energy efficiencies of heating systems in dwellings [4]. Countries should also consider regulatory measures for heating system upgrades and replacements, subsidy schemes and audit programmes

Any cause for repair should also an opportunity for optimization and/or modernization with optimization measures should be executed before introducing any expensive technology is contemplated.

Educational provision should enable plumbing craftsmen to take responsibility and be held accountable for the design and certification of heating systems in dwellings similar to that of an engineer under statutory instruments such as ‘Building Control Regulations’ [60].

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