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An unfavorable indoor environment as mediator between fuel poverty and health: an exploration

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Abstract
Aim The objective of this study is to gain insight into the extent to which an unfavorable indoor environment mediates the association between fuel poverty and health.
Method Data from the 2022 Dutch Health Survey were enriched with some registration data from the 2020 Monitor Fuel Poverty, resulting in a study population of 16,210 adults. Using Structural Equation Modeling in R, the mediation effect of an unfavorable indoor environment on the relationship between fuel poverty and various health outcomes was examined. An unfavorable indoor environment was defined as moisture, mold, and/or inadequate ventilation, as indicators of housing quality. Analyses were adjusted for various demographic factors: age, gender, property ownership (tenants or not), level of education, household with or with no children, and level of urbanity of the residence.
Results Fuel poverty is negatively associated with the absence of mental health issues and with social capital and positively associated with the risk of anxiety or depression, a negative self-rated health, physical limitations in daily life, loneliness, and stress. These associations are partially mediated by an unfavorable indoor environment (mediation proportion: 5.5–10.8%). In a subgroup analysis of tenants of housing corporations, the mediation proportion ranges from 8.3 to 20.1%.
Conclusion An unfavorable housing quality with moisture, mold, and/or inadequate ventilation is a mediating factor in the relationship between fuel poverty and health. Addressing the health effects of fuel poverty requires a comprehensive and structural approach, of which the indoor environment is an integral part. Connecting fuel poverty, housing quality, and health is necessary in both research and policy addressing fuel poverty.

Keywords Fuel poverty · Public health · Moisture and mold · Ventilation · Tenants

Introduction

Because of the high energy prices during the winter of 2022–2023, fuel poverty requires extra attention [1]. Prior to the 2020 energy crisis, 6.4% of Dutch households were considered to be fuel poor [2]. By the end of 2022, this estimate was 7.4%, thereby accounting for government financial assistance. Fuel poverty is defined as low income combined with either high energy costs or low home energy efficiency due to inadequate insulation [3]. The majority (68%) of fuel-poor households reside in properties rented from housing corporations. This makes tenants of these housing corporations a high-risk group for fuel poverty. Unlike homeowners, who can benefit from subsidies for home insulation, these tenants rely on the corporations for structural improvements to their

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homes. Furthermore, single-person households and single-parent families are overrepresented among fuel-poor households. In the Netherlands, neighborhoods with a relatively high prevalence of fuel-poor households are dispersed across major cities and the countryside in different regions [4]. The increase in fuel poverty by the end of 2022 was particularly prominent among families [3]. During the winter of 2022–2023, there was an increase in inquiries to the Public Health Services regarding moisture and mold in homes in relation to health complaints. Media attention to this issue triggered debates in the Dutch Parliament [5, 6]. Inadequate heating of homes due to fuel poverty can lead to increased mold, mold-related odors, and moisture [7]. Improving home insulation to address fuel poverty can have positive effects on moisture and mold, provided there is simultaneous attention to adequate ventilation [8]. An unfavorable indoor environment in homes, defined as moisture, mold, and/or inadequate ventilation, could be meaningful in understanding the relationship between fuel poverty and health.

Fuel poverty negatively affects both mortality and morbidity [1]. Cold stress can lead to respiratory and cardiovascular conditions, compromised immune resistance resulting in infections, and exacerbation of existing chronic conditions, particularly arthritis, rheumatism, and asthma. Older adults are particularly vulnerable to cardiovascular conditions due to reduced body temperature regulation and existing health issues [1, 9–11]. Youth are more susceptible to the effects of fuel poverty due to the development and exacerbation of respiratory complaints [1], leading to increased healthcare costs [12]. The adverse health effects of moisture, mold, and/or inadequate ventilation primarily include the onset and exacerbation of asthma, respiratory complaints, and respiratory infections [13, 14]. Besides differences between age groups, there are differences based on gender and socioeconomic status (SES). Women spend more time indoors, making them more vulnerable to the health effects of fuel poverty and an unfavorable indoor environment than men [1]. Households with a lower SES are more prone to fuel poverty, leading to increased exposure to an unfavorable indoor environment combined with reduced affordability and accessibility of solutions [10]. Chronic financial stress about basic needs such as gas and electricity for cooking, showering, and heating adversely affects both physical and mental health [10, 15]. This chronic stress diminishes resilience and demands coping skills [10, 16]. Fuel poverty negatively impacts overall well-being and can lead to the onset or exacerbation of anxiety disorders or depression [1, 9, 11, 17]. It also affects residents' social relationships, because of shame about their living conditions and distrust towards others, leading to or exacerbating social isolation and lack of social support [9, 10, 18].

Based on their systematic review, Wang, Wang, and Nörback concluded that fuel poverty is usually studied in relation to health and that moisture, mold, and ventilation in relation to health have been studied separately [8]. However, research that includes fuel poverty, a detrimental indoor environment, and health is scarce. This leads to the exploratory research question in this article: To what extent is an unfavorable indoor environment a mediator in the relationship between fuel poverty and health, in the general population and the high-risk group of tenants of housing corporations?

Method

In this study, registration data from the Statistics Netherlands' Monitor Fuel Poverty for the most recent available year (2020) were used. In this Monitor Fuel Poverty, data are available for almost all Dutch households and residents [2]. Honoring General Data Protection Regulation requirements, these data were linked at the individual level in the Statistics Netherlands microdata environment to data from the Dutch Health Survey for adults and the elderly, which was conducted in the fall of 2022. This Health Survey was distributed among a representative sample of residents aged 18 years or older and included a regional module with additional questions about the living environment in the Public Health Services area where this research was conducted. This regional module includes several questions about housing quality with regard to moisture, mold, and inadequate ventilation. The studied Public Health Services area consists of 16 municipalities, ranging from highly urbanized to nonurbanized. From existing datasets, variables necessary to answer the research question in this article were selected. The choice of these variables was based on the literature as described in the introduction. The majority of variables were self-reported, with the exception of fuel poverty and ownership, which were derived from registration data.

Tab. 1 provides the operationalization of the variables included in this study with regard to fuel poverty, unfavorable indoor environment, demographic characteristics included as covariates in the study, and various health outcome measures. For fuel poverty, a combined measure was chosen to assess the total group in fuel poverty in this exploratory study. Both high energy costs combined with a low income and a poorly insulated home combined with a low income were considered. Therefore, by definition, low-income households that keep their heating low or off (low energy costs) but live in a poorly insulated home were included. As part of the SES, educational level was included as a demographic characteristic. Since the income variable is included in the definition of fuel poverty, it was not included as a separate covariate. Based on the literature listed in the introduction, health measures were chosen for

Table 1 Operationalization of the variables

Variable	Operationalization
Fuel poverty	
LIHE and/or LILEK	Low income, high energy costs (LIHE) and/or low income, low energy quality of the home (LILEK), defined in the Monitor Fuel Poverty as a dichotomous variable: fuel poverty (*no* or *yes*) [2]. (See Table in [2] for technical explanations of data sources, definitions, and calculations.)
Unfavorable indoor environment	
Moisture, mold and/or inadequate ventilation	Combination of two questions from the regional module of the Health Survey about living environment, concerning the respondent's housing quality in the past 12 months. Respondents are asked to indicate their agreement with the following two statements: "There are mold or moisture spots in my living or sleeping room" and "I think I can ventilate my house sufficiently." When respondents agreed with the statement about mold or moisture spots and/or disagreed with the statement about sufficient ventilation of the house, this was considered as an unfavorable indoor environment. This resulted in a dichotomous variable: unfavorable indoor environment (*no* or *yes*)
Demographic characteristics	
Age	The Health Survey was enriched with data from Statistics Netherlands. Respondent's age was measured in years, with reference date September 1, 2022. This resulted in a continuous variable
Gender	The Health Survey was enriched by Statistics Netherlands with the respondent's gender, resulting in a categorical variable: *male* or *female*
Ownership	This variable originates from the Monitor Fuel Poverty [2]. This variable distinguishes between tenants of housing corporations, tenants of private landlords, and homeowners
Educational level	Education is inquired in the Health Survey with one question: "What is your highest completed education (with diploma or certificate)?" Respondents can choose from eight answer options. Additionally, data were enriched by Statistics Netherlands with education level, after which both variables were combined to create a complete variable. This resulted in an ordinal variable: *low educational level* (lower secondary education, lower vocational education), *middle educational level* (higher secondary education, preuniversity education, intermediate vocational education), and *high educational level* (higher vocational education, university)
Household with/with no children	This was inquired with the question: "Which persons do you currently live with?" Different and multiple answers are possible, resulting in different variables for household composition. For this research, we used a categorical variable with two categories: *household with* or *with no children living at home*
Level of urbanity of residential municipality	The level of urbanity of the respondent's residential municipality was added to the dataset based on the environmental address density of the municipality where the respondent resides. This resulted in an ordinal variable with five categories, ranging from *extremely urban* (1) to *nonurban* (5)
Health measures	
Score no mental health issues	This variable was measured with the MHI 5, an international standard for measuring mental health. The MHI 5 consists of five questions, relating to how one has felt in the past four weeks. There are six answer options, ranging from *constantly* to *never*, with a corresponding score ranging from 0 to 5. This score is multiplied by four, resulting in a sum score ranging from 0 (*very unhealthy*) to 100 (*perfectly healthy*). A score of 60 or higher indicates good mental health [19]
Risk score for anxiety disorder or depression	This variable was measured with the Kessler-10, a screening instrument for psychological distress. The instrument was translated and validated in the Dutch population and consists of ten items, identifying whether a respondent felt nervous, tired, hopeless, restless, down, depressed, or worthless in the past four weeks [20]. Answer options are displayed on a five-point Likert scale, ranging from *never* to *always*. This resulted in a sum score ranging from 10 to 50 points, with a higher score indicating a higher risk of anxiety disorder or depression
Stress	Stress was inquired with the following question: "Have you experienced stress in the past four weeks?", with four answer options, ranging from *no, (almost) not* to *yes, a lot of stress*. This resulted in a dichotomous measure, distinguishing between respondents who experienced (a lot of) stress in the past weeks and respondents who had experienced no or little stress in the past four weeks
Negative self-rated (perceived) health	This variable was measured with one subjective question: "How is your health in general?" There were five answer options, resulting in three categories. Self-rated health can be effectively measured using one item and provides a good impression of the subjective assessment someone gives to his or her health in general [21]. This resulted in an ordinal variable: *experienced health is very good or good, experienced health is fair*, and *experienced health is poor or very poor*. A higher score indicates a more negative (poorer) experienced health
Physical limitations	This variable was measured by two questions: "Are you limited in your daily life because of health problems?" and "Has this limitation lasted for half a year or longer?" This resulted in an ordinal variable with three outcome categories: *no, not limited at all or (severely) limited, but for less than half a year*; *limited in daily life for half a year or longer because of health problems*; and *severely limited in daily life for half a year or longer because of health problems*
Social capital	Social capital refers to the level of social cohesion in the neighborhood. This was measured using five different statements about interaction in the neighborhood. Respondents were asked to what extent they agree with these statements using five answer options, resulting in a sum score with a range from 5 to 25, where a higher score indicates a higher social capital
Loneliness	Loneliness was measured with the De Jong Gierveld Loneliness Scale [22]. This scale consists of eleven items with three answer options, asking to what extent certain statements apply to the respondent (e.g., "I miss people around me" or "I miss a really good friend"). Answer options are *yes, somewhat*, and *no*, where *yes* and *somewhat* receive a score of 1 and *no* receives a score of 0, resulting in a sum score with a range from 0 to 11

Table 2 Description of study population stratified by fuel poverty and total unweighted and weighted data

Variable		No fuel poverty (unweighted data)	Fuel poverty (unweighted data)	Total (unweighted data)	Total (weighted data)
Fuel poverty (%, *n*)				2.4% (384)	3.5% (15,978)
Unfavorable indoor environment (%, *n*)		10.8% (1704)	21.9% (84)	11.0% (1788)	12.8% (60,672)
Age (M, SD)		59.8 (16.9)	62.1 (17.2)	59.9 (16.9)	51.91 (18.57)
Gender (%, *n*)	Female	51.7% (8179)	61.7% (237)	51.9% (8416)	50.7% (233,389)
Ownership (%, *n*)	Tenants of housing corporations	14.7% (2321)	61.2% (235)	15.8% (2556)	19.8% (91,070)
	Tenants of private Landlords	4.8% (760)	18.2% (70)	5.1% (830)	6.0% (27,457)
	Homeowners	80.5% (12,745)	20.6% (79)	79.1% (12,824)	74.2% (341,454)
Educational level (%, *n*)	Low	35.5% (5548)	65.0% (245)	35.7% (5793)	30.5% (140,089)
	Middle	32.3% (5049)	23.9% (90)	31.7% (5139)	34.9% (160,594)
	High	32.2% (5032)	11.1% (42)	31.3% (5074)	33.5% (154,203)
Household with children (%, *n*)		24.4% (3823)	16.7% (63)	24% (3886)	32.4% (153,790)
Level of urbanity of residential municipality (%, *n*)	2 = highly urban	50.9% (8048)	52.2% (201)	50.9% (8249)	58.6% (269,462)
	3 = moderately urban	4.2% (671)	3.6% (14)	4.2% (685)	3.4% (15,531)
	4 = low urban	37.6% (5955)	38.8% (149)	37.7% (6104)	35.5% (163,148)
	5 = nonurban	7.3% (1152)	5.2% (20)	7.2% (1172)	2.6% (11,840)
No mental health issues (M, SD)		0.78 (0.16)	0.69 (0.29)	0.78 (0.16)	0.75 (0.17)
Risk of anxiety disorder or depression (M, SD)		0.33 (0.13)	0.41 (0.17)	0.33 (0.13)	0.35 (0.15)
Stress (M, SD)		0.13 (0.33)	0.20 (0.40)	0.13 (0.34)	0.18 (0.38)
Self-rated health (%, *n*)	Very good or good	68.3% (10,781)	42.0% (161)	67.5% (10,942)	68.6% (315,372)
	Fair	26.5% (4181)	43.3% (166)	26.8% (4347)	25.2% (115,796)
	Poor or very poor	5.2% (828)	14.6% (56)	5.5% (884)	6.1% (28,012)
Physical limitations (%, *n*)	No limitations or (severe) limitations but for a period shorter than half a year	66.0% (10,241)	46.6% (173)	64.2% (10,414)	68.06% (323,144)
	Limitations but not severe for half a year or longer	29.9% (4633)	43.9% (163)	29.6% (4796)	26.43% (125,500)
	Severe limitations for half a year or longer	4.2% (646)	9.4% (35)	4.20% (681)	4.19% (19,879)
Social capital (M, SD)		20.32 (3.91)	18.72 (4.47)	20.29 (3.93)	19.57 (4.05)
Loneliness (M, SD)		3.09 (3.32)	4.69 (3.81)	3.13 (3.34)	3.30 (3.45)

M mean, *SD* standard deviation

mental, physical, and social health. The individual chronic limitations described in the introduction as relevant (arthritis, rheumatism, asthma, cardiovascular conditions) are not measured in the Health Survey. However, the variable physical limitations was included, which measures overall limitations in daily life because of chronic conditions, as well as the variable self-rated poor health, which is associated with chronic conditions.

The response to the Health Survey in the research area was 24% for adults (aged 18–64 years) and 45% for the elderly (aged 65+ years). To correct for selective nonresponse, Statistics Netherlands calculated weight factors. The following variables were used to derive these weight factors: gender, age, marital status, country of origin, household size, income, and municipality. Both the unweighted and weighted percentages and averages of the variables included in this study were calculated. In total, 19,214 respondents in the research area completed the Health Survey, of whom 17,536 could be individually linked to the registration data from the Monitor Fuel Poverty. Because of missing values in the fuel poverty and unfavorable indoor environment variables, the analyses were conducted for a research population of 16,210 respondents. Data from the Monitor Fuel Poverty are available at the household level, whereas data from the Health Survey are measured at the individual level.

A first step in data processing was linking individuals to their respective households, to ensure availability of all data at the individual level. Subsequently, a descriptive analysis was carried out on both the weighted and the unweighted data. Further, the population was stratified by fuel poverty using the unweighted data. Then, a correlation matrix was visualized to explore the correlation coefficients

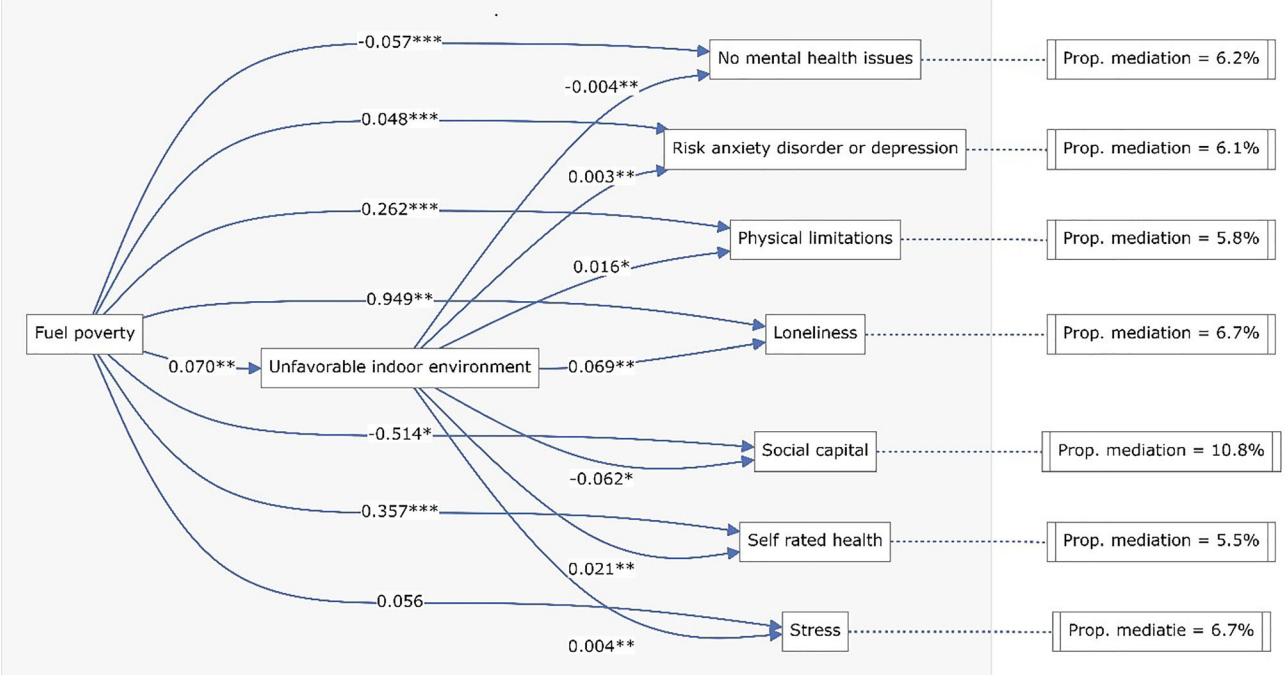

Fig. 1 The effect size of fuel poverty directly and mediated through unfavorable indoor environment in a multivariate regression model (SEM) and the proportion of mediation for various health measures in the total study population (N = 16,210), after controlling for differences in demographic characteristics. (*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$)

(Pearson and Spearman) between the variables at the ordinal and numeric level of measurement. A Structural Equation Modeling (SEM) approach was used to further investigate the relationships between the variables and their interdependencies. With the unweighted data, a regression model was developed using R, with the lavaan package 0.6–16. SEM allows for the simultaneous modeling of multiple dependent variables and predictors, thus enabling the examination of the mediation effect of the unfavorable indoor environment variable on the relationship between fuel poverty and various health measures. To apply SEM to all health measures, the scale scores were harmonized. The scale score for no mental health issues was divided by 100, whereas the scale score for social capital was divided by 25. The range of measurement levels of the outcome variables in the SEM regression model is diverse, comprising continuous, ordinal, and binary health measures. The model was constructed to estimate all outcome measures while considering their interdependencies, and the variables fuel poverty and unfavorable indoor environment were used as predictors. Additionally, demographic characteristics (see Tab. 1) were included in the model as control variables. The lavaan package, within the SEM function, employs the Diagonally Weighted Least Squares (DWLS) method for estimating the model. This method is suitable for a mix of continuous, ordinal, and binary measured variables, providing robust estimations even when the data are not normally distributed. The lavaan package utilizes the Weighted Least Squares Mean and Variance adjusted (WLSMV) estimator for this purpose. DWLS is used to estimate model parameters, while simultaneously calculating robust standard errors and an adjusted test statistic for the different measurement levels of the model through WLSMV. The effect sizes of the health measures were calculated, and the mediation proportion was calculated as the indirect effect via the unfavorable indoor environment as a proportion of the total effect (directly from fuel poverty plus indirectly via unfavorable indoor environment) on the health measure. SEM regression analyses were performed for the total research population and separately for the high-risk group of tenants of housing corporations, and unstandardized effect sizes were calculated. The results of the analyses are graphically displayed using DAGitty 3.1. To compare the effects on the different health outcome measures, standardized effect sizes were also calculated, and they are presented in tabular form in the appendix, along with the unstandardized effect sizes.

Results

Of the study population, 2.4% live in fuel poverty (weighted percentage: 3.5%), 11% experience an unfavorable indoor environment (weighted: 12.8%), and 15.8% reside in a rental property managed by a housing corporation (weighted: 19.8%) (see “total” columns in Tab. 2). In Tab. 2, unweighted data are also stratified by fuel poverty. Among the respondents living in fuel poverty, 61.2% reside in a rental property managed by a housing corporation, and 65%

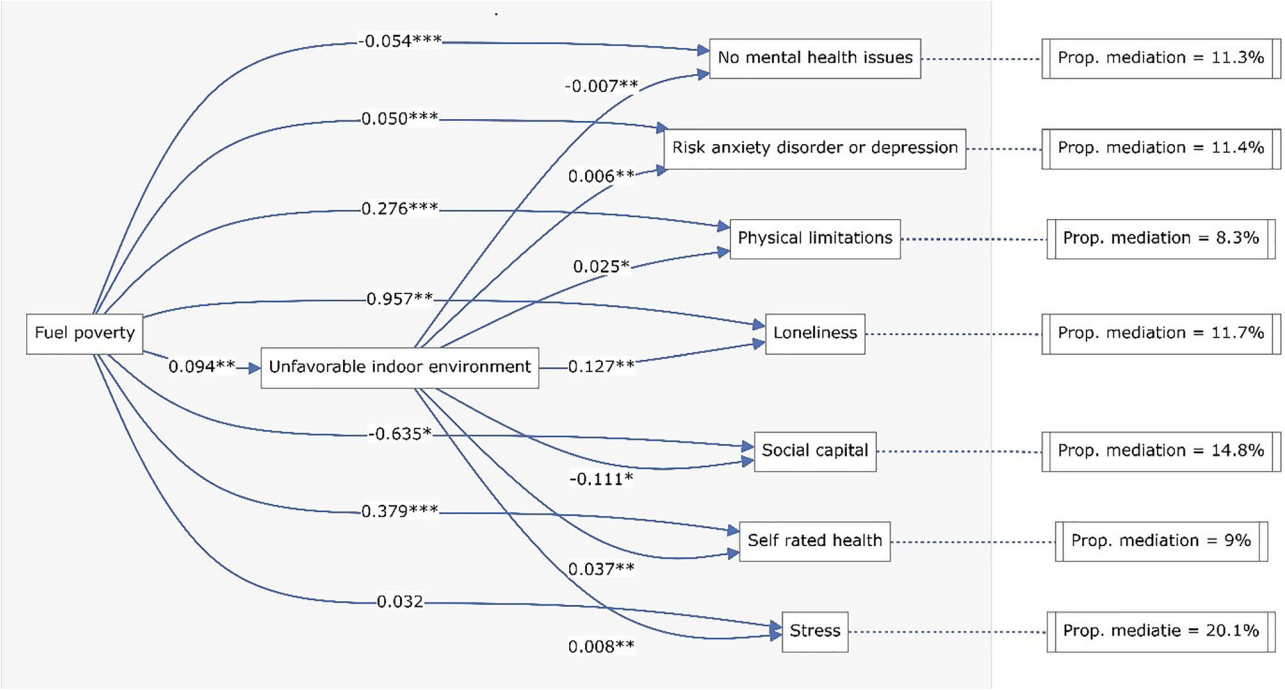

Fig. 2 The effect size of fuel poverty directly and mediated through unfavorable indoor environment in a multivariate regression model (SEM) and the proportion of mediation for various health measures in the subgroup of tenants of housing corporations ($n = 3734$), after controlling for differences in demographic characteristics. (** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$)

have a low educational level (compared with 14.7 and 35.5%, respectively, of those not living in fuel poverty). Additionally, 21.9% of the respondents living in fuel poverty experience an unfavorable indoor environment, compared with 10.8% of the respondents not living in fuel poverty. Of the respondents in fuel poverty, 14.6% rate their own health as (very) poor, compared with 5.2% of the respondents not living in fuel poverty. In addition, for other health outcomes, such as stress (mean (M): 0.2; standard deviation (SD): 0.4) and risk of anxiety disorder or depression (M: 0.41; SD: 0.17), respondents living in fuel poverty have worse outcomes than those not living in fuel poverty (stress, M: 0.13; SD: 0.33 and risk of anxiety disorder or depression, M: 0.33; SD: 0.13).

Appendix 1 visualizes the positive (blue) or negative (red) associations between the variables in the study with ordinal or numeric measurement levels (see digital additional content). The health measures absence of mental health issues and risk of anxiety disorder or depression show a relatively strong association with each other, and stress and loneliness exhibit a moderate association with these indicators of mental health as well. Additionally, self-rated (perceived) health is strongly associated with physical limitations in daily life. Demographic characteristics also show moderate associations with each other, for example, age and household with children, and age and level of education. Fuel poverty and an unfavorable indoor environment have low correlations with both demographic characteristics and health outcomes.

Figure 1 presents the results of the SEM regression analysis for the entire study population, as effect sizes (regression coefficients). The SEM regression model provides an estimate of the effect of fuel poverty and unfavorable indoor environment on the various health measures, taking into account their interdependencies. These effects were adjusted for differences in demographic characteristics. Fuel poverty is negatively associated with no mental health issues and social capital and positively associated with the risk of anxiety disorder or depression, physical limitations in daily life, loneliness, stress, and perceived negative (poor) health. The effect of fuel poverty on the various health outcomes is partially mediated by an unfavorable indoor environment. As an example: The direct effect size of fuel poverty on self-rated health is 0.357, and the indirect effect size of fuel poverty through unfavorable indoor environment is 0.021. Of the total effect of 0.378, 5.5% is mediated through an unfavorable indoor environment. The proportion of mediation by an unfavorable indoor environment varies for the different health outcomes between 5.5 and 10.8%. From the standardized effect sizes (Appendix 2, see digital additional content), it is evident that fuel poverty has the greatest effects on the risk of anxiety disorder or depression (standardized total effect: 0.058), the absence of mental health issues (–0.057), and perceived negative (poor) health (0.054).

The same analyses as shown in Fig. 1 were conducted for the subgroup of tenants of housing corporations (see Fig. 2). Once again, fuel poverty has a neg-

ative association with the absence of mental health issues and social capital. The positive associations between fuel poverty and the risk of anxiety disorder or depression, physical limitations in daily life, loneliness, and perceived negative health are also found in this subgroup. However, the effect of fuel poverty on stress is no longer statistically significant. The mediation effect appears to be larger among tenants of housing corporations compared with the entire study population, with the proportion of the effect mediated through the unfavorable indoor environment ranging from 8.3 to 20.1%. From the standardized outcomes (Appendix 2, see digital additional content), it is evident that among the subgroup of tenants of housing corporations, fuel poverty has the greatest effect on perceived negative health (standardized total effect: 0.118), followed by, in terms of standardized effect size, the risk of anxiety disorder or depression (0.104) and the absence of mental health issues (–0.095).

Discussion and conclusion

Fuel poverty is negatively associated with social capital and the absence of mental health issues and positively associated with the risk of anxiety disorder or depression, physical limitations in daily life, loneliness, perceived negative health, and stress. The greatest effects of fuel poverty on health are seen for mental health issues, risk of anxiety disorder or depression, and perceived negative health. These associations are partially mediated by an unfavorable indoor environment, with the proportion of mediation ranging from 5.5 to 10.8%. In the subgroup of tenants of housing corporations, the effect of fuel poverty is greatest on perceived health. The proportion of mediation via an unfavorable indoor environment is higher in this subgroup, ranging from 8.3 to 20.1%.

Strengths

A strength of the current study is the inclusion of both fuel poverty and an unfavorable indoor environment, along with various health outcomes, in one study. Furthermore, the analyses accounted for their interdependencies, and effect sizes were adjusted for differences in relevant demographic characteristics. The research findings in this article are exploratory and need to be followed up by other types of studies: longitudinal and intervention research. Van der Wal, Van Ooij, and Straver investigated the effects of the use of so-called energy fixers/coaches, renovations, and schemes to subsidize the purchase of washing machines or kitchen appliances on moisture and mold, physical and mental health, and social connectedness in the neighborhood in an intervention group and control group [23]. The various support measures as part of fuel poverty policy improve health and neighborhood connectedness, indicating causal relationships; however, households still suffer from cold, moisture, and mold in their homes. Additionally, health problems do not disappear completely. This is consistent with the findings in this article, where a mediation effect of an unfavorable indoor environment is present but of limited magnitude. In the total study population, a maximum of 10.8% of the effect of fuel poverty on health is mediated indirectly through the indoor environment; in the subgroup of tenants of housing corporations, this is a maximum of 20.1%. These mediation proportions indicate that there are other factors of importance in the relationship between fuel poverty and health [24]. Furthermore, from lived experiences, it is known that fuel poverty can be associated with general poverty and related challenges such as not having enough money to cook food, potentially leading to food shortages, or avoiding healthcare because of the cost, with potential health consequences [15]. Addressing the health effects of fuel poverty requires a broader and structural approach, with indoor environment being one element of that approach. Tenants of housing corporations are an important target group for fuel poverty policy in relation to health and the indoor environment in homes.

Limitations

Limitations of this study include the following. An unfavorable indoor environment was self-reported and not actually measured with equipment. It is known that the risk perception of moisture and mold is limited [7]. Severe moisture and mold problems lead to odor and visual discomfort, whereas adverse health effects can already occur with mold spores. It is possible that the limited risk perception influenced the measured effect sizes. Therefore, other types of studies that involve actual home measurements are needed.

Another study limitation that can lead to underestimation of effects is the selective nonresponse to the Health Survey. Despite inclusion of demographic characteristics as covariates in the analyses, the most vulnerable people to fuel poverty, i.e., those who experience daily stress to meet basic needs, are unlikely to complete the Health Survey. An indication of this is that the weighted percentage of Health Survey respondents who are fuel poor is 3.5% in the research area, whereas the national average based on registration data is 6.4%.

Additionally, the fact that data from 2020 were used to assess fuel poverty and the Health Survey data are from 2022 suggests a possible underestimation of the effects, as fuel poverty increased after 2020. Finally, in this exploratory research, the consequences of fuel poverty and moisture, mold, and/or inadequate ventilation for health have been highlighted. However, the consequences of hot weather should not be forgotten [25]. In policy and practice, it is important to take

insulation measures and pay attention to ventilation, which promotes health both in cold and hot weather.

Based on this exploratory study, we have the following suggestions for further research. The first suggestion is to use Statistics Netherlands data on medication prescriptions to ensure more accurate assessment of the chronic diseases measured in this study by the general variables physical limitations and negative self-perceived health. The second suggestion is to further break down the combined measure of fuel poverty used in this study into the effects of low income with high fuel bills and/or poorly insulated homes and the interactions between them in a study with a larger population. Within this framework, it is also interesting to study households in well-insulated homes with moisture and mold, as ventilation behavior may play a greater role in this subgroup than in others. Additionally, subpopulations such as families with children and seniors deserve extra attention in a study with a larger population.

In conclusion, the perspective of the relationship between health and moisture, mold, and/or inadequate ventilation in homes is not self-evident in fuel poverty policy [15, 26]. There is a need for a stronger connection between fuel poverty, moisture, mold, inadequate ventilation, and health, in both research and policy.

References

1. Champagne SN, Phimister E, Macdiarmid JI, et al. Assessing the impact of energy and fuel poverty on health: a European scoping review. Eur J Public Health. 2023;33:764–70.
2. Statistics Netherlands. Monitor Energiearmoede in Nederland, 2019 en 2020. https://www.cbs.nl/nl-nl/maatwerk/2023/04/monitor-energiearmoede-2020. Accessed 21 Mar 2024, Monitor Fuel Poverty in the Netherlands, 2019 and 2020.
3. Mulder P, Batenburg A, Longa DF. Energiearmoede in Nederland 2022: een actuele inschatting op nationaal en lokaal niveau [Fuel Poverty in the Netherlands: Current estimation on national and local level. Amsterdam: TNO; 2023.
4. Mulder P, Longa DF, Straver K. De feiten over energiearmoede in Nederland: inzicht op nationaal en lokaal niveau [Facts about fuel poverty in The Netherlands: insight at the national and local level. Amsterdam: TNO; 2021.
5. Nieuws RTL. Honderdduizenden huishoudens zetten kachel lager: huizen vol schimmel tot gevolg [Hundreds of thousands of households lower their heaters: homes full of mold as a result. https://www.rtlnieuws.nl/nieuws/video/video/5362714/honderdduizenden-nederlanders-zetten-kachel-lager-huizen-vol-schimmels. Accessed 21 Nov 2023.
6. Rijksoverheid. Antwoorden op kamervragen over energiearmoede en schimmel in woningen [Responses on questions regarding fuel poverty and mold from the Dutch Parliament. https://www.rijksoverheid.nl/documenten/kamerstukken/2023/02/23/antwoorden-op-kamervragen-over-energiearmoede-en-schimmel-in-woningen. February 1, 2023.
7. Sharpe RA, Thornton CR, Nikolaou V, et al. Fuel poverty increase risk of mould contamination, regardless of adult risk perception and ventilation in social housing properties. Environ Int. 2015;79:115–29.
8. Wang C, Wang J, Nörback D. A systematic review of associations between energy use, fuel poverty, energy efficiency improvements and health. Int J Environ Res Public Health. 2022;19:7393.
9. Marmot Review Team (UK). The health impacts of cold homes and fuel poverty. London: Marmot Review Team; 2011.
10. Jessel S, Sawyer S, Hernández D. Energy, poverty, and health in climate change: a comprehensive review of an emerging literature. Front Public Health. 2019;7:357.
11. Bentley R, Daniel L, Li Y, et al. The effect of energy poverty on mental health, cardiovascular disease and respiratory health: a longitudinal analysis. Lancet Reg Health West Pac. 2023;35:100734.
12. Van Maurik R, Mulder P, Verstraten P. Gezondheidskosten en energiearmoede: een empirische analyse voor Nederland [Health care costs and fuel poverty: an empirical analysis in the Netherlands. Amsterdam: TNO; 2023.
13. RIVM. GGD-richtlijn medische milieukunde: schimmel- en vochtproblemen in woningen [Public Health Services: guideline medical environmental health: mold and moisture in homes. Bilthoven: RIVM; 2012.
14. Coulburn L, Miller W. Prevalence, risk factors and impacts related to mould-affected housing: an Australian integrative review. Int J Environ Res Public Health. 2022;19:1854.
15. Stoopendaal M, van Loon L. Een ongezond binnenmilieu ten gevolge van energiearmoede onder huurders: welke keuzes worden gemaakt en waarom? [An unhealthy indoor environment due to fuel poverty among tenants: what choices are made and why? Arnhem: Academische Werkplaats Gezonde Leefomgeving; 2023.
16. Evans J, Hyndman S, Stewart-Brown S, et al. An epidemiological study of the relative importance of damp housing in relation to adult health. J Epidemiol Community Health. 2000;54:677–86.
17. Liddell C, Guiney C. Living in a cold and damp home: frameworks for understanding impacts on mental well-being. Public Health. 2015;129:191–9.
18. Baudaux A, Bartiaux F. Energy poverty and social assistance in the Brussels-Capital Region. Brussels: Brussels Studies; 2020.
19. Driessen M. Geestelijke ongezondheid in Nederland in kaart gebracht: een beschrijving van de MHI 5 in de gezondheidsmodule van het Permanent Onderzoek Leefsituatie [Mental issues in the Netherlands: a description of the MHI 5 in the health module of the permanent survey of living conditions. The Hague: Stat Netherlands; 2011.
20. Donker T, Comijs H, Cuijpers P, et al. The validity of the Dutch K10 and extended K10 screening scales for depressive and anxiety disorders. Psychiatry Res. 2010;176:45–50.

21. Wu S, Wang R, Zhao Y, et al. The relationship between self-rated health and objective health status: a population-based study. BMC Public Health. 2013;13:320.
22. Van Tilburg TG, de Jong-Gierveld J. Cesuurbepaling van de eenzaamheidsschaal [Cut-off determination of the loneliness scale. GEEG. 1999;30:158–63.
23. van der Wal A, van Ooij C, Straver K. Effecten van fixers/energiecoaches, renovaties en witgoedregelingen [Effects of fuel fixers/coaches, renovations, and schemes to subsidize the purchase of washing machines or kitchen appliances. Amsterdam: TNO; 2023.
24. RIVM. Volksgezondheid Toekomst Verkenning [Public Health Foresight]. https://www.vzinfo.nl/ziektelast-in-dalys/bijdrage-risicofactoren. Accessed 21 Nov 2023.
25. Kragt A, Willems J, van Ginkel J, et al. Handreiking verduurzaming van woningen en gezondheid [Guidelines for sustainable housing and health. https://awgl.nl/images/projecten/2020/Informatie_blad_verduurzaming_en_gezondheid_versie_10.pdf. Accessed 21 Nov 2023.
26. Bonderup S, Middlemiss L. Mould or cold? Contrasting representations of unhealthy housing in Denmark and England and the relations to energy poverty. Energy Res Soc Sci. 2023;102:103176.