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ORIGINAL ARTICLE

# Housing retrofit as an intervention in thermal comfort practices: Chinese and Dutch householder perspectives

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**Abstract** Contemporary packages of housing retrofit equipment are based on models of expected energy savings with regard to globally standardized thermal comfort levels. Previous research shows that the energy savings realised after a housing retrofit is substantially lower than expected. Attempts to reduce energy demand by physical re-design, utilising technical standards for thermal comfort as well as financial incentives, tend to ignore the role of retrofit interventions in the construction of everyday practices of thermal comfort making. Thermal comfort practices of heating, cooling and ventilation are moderated by specific householders' motivations which constitute 'wants' and emerging 'needs' in the interaction with the housing retrofit equipment. This paper proposes that the interactions between the retrofitted buildings and the householders are the sum of material affordances, as signified by the design of the housing equipment on the one hand, and the practical affordances in practices-as-performances on the other. The study presents comfort practices in relation to recently retrofitted low-income housing estates in Beijing, Mianyang (Sichuan province, South-west China) and Amsterdam on the basis of 50 qualitative interviews with householders in each city. The paper concludes that the expected energy saving is counteracted by a poor match between conventional retrofit packages and householders' considerations about their thermal comfort. To better reduce energy demand and to mitigate energy poverty, retrofit packages should provide adaptive thermal comfort as preferred by householders, rather than fixed or tightly specified thermal comfort. Such a perspective may support a more flexible and inclusive use of housing equipment as part of retrofit programs.

**Keywords** Housing retrofit · Housing equipment · Affordances · Thermal comfort · Social practices · Energy saving · Amsterdam · Beijing · Mianyang

**Highlights**

- Thermal comfort should not be treated as fixed but as an adaptive social construct.
- Considerations about thermal comfort vary widely among China and the Netherlands.
- Current retrofit policies in China and the Netherlands externalise relations between householders and technologies.
- Retrofit packages need to fit with existing and emerging thermal comfort practices.

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## Introduction

A recent study revealed that after energy retrofitting of housing complexes, the realized energy savings are 30–40% lower than theoretically expected (Sunikka-Blank and Galvin 2012; Galvin and Sunnika-Blank 2017). This substantial lower energy saving in the building improvement is largely attributable to different understandings of thermal comfort between experts' (building installation engineers, architects and government regulators) on the one hand and householders on the other (Hinton 2010). An explanation for the gap between theory and practice is the application of a strict techno-economic approach to retrofitting which focuses on globally standardised indoor comfort levels (Moezzi and Janda 2014). Due to the variety of existing and emerging indoor comfort levels within and between households, the energy use in identical homes can vary by a factor of 3 to 4 (Gram-Hanssen 2010). This seems to reveal a poor understanding of the role of householders in retrofit provision (IPCC 2014).

When retrofit providers frame indoor comfort as a definable condition, the conventional logic is to retrofit indoor environments that deliver it (Guy and Shove 2000; Van Vliet et al. 2005). Designers of conventional housing retrofit equipment for energy saving assume that the householders use the house and surroundings as 'intended' after the improvement of wall insulation, window attributes, installations of heating, mechanical ventilation and cooling (Macrorie et al. 2015). Globally standardised indoor comfort levels are mostly based on a fixed definition of thermal comfort, like setting a comfort zone of 18 to 21 °C (Chappells and Shove 2005; Wilhite 2009). Assuming a 'one-size-fits-all' thermal comfort level potentially underestimates other thermal comfort motivations, including domestic well-being, health, control, familiarity, tradition, costs and beauty, which determine energy demand and 'normal' daily life (Ellsworth-Krebs et al. 2015; Cherry et al. 2017). Understandings of energy demand as being accommodated in wider socio-material systems would lead to a broader range of strategies of retrofit. For instance, with an alternative and broader view, energy retrofitting would take into account social conventions, differentiated meanings of thermal comfort, location of activity, moving around the house, food, bedding and clothing, instead of only building insulation or energy saving appliances (Maller and Strengers 2014).

Householders are knowledgeable agents in achieving thermal comfort in their home and surroundings (Chappells and Shove 2005). They take actions to reach the thermal comfort they want. They are not just passive receivers of externally provided packages of retrofit equipment that affect their apartments (Strengers 2008; Winther and Wilhite 2015). Therefore, when thermal comfort is conceived as an achievable condition from a householder perspective, attention should be turned to evolving everyday activities for achieving thermal comfort or solving discomfort by a range of thermal comfort practices like heating, ventilation and cooling (Tweed et al. 2014; Hitching et al. 2015). Householders' activities to achieve thermal comfort are shaped by social conventions, fellow dwellers and by competences and motivations to work with the options their housing equipment offers.

The concept of affordances may help to capture the meaningful social and operational relationship of householders with their retrofitted material environment as performed in their actual consumption practices. In this study, the concept of 'affordances' refers to the actual technical possibilities or obstacles of the material retrofit environment in the context of practical action of householders at hand (Ingold 1992, 2000, 2018). This highlights the urgent need for an integrated approach to housing retrofitting that combines changes of action possibilities in technical features and conditions with a parallel re-shaping of householders' views and practices to achieve real and lasting reductions in energy use (Jensen et al. 2018). Subsequently, the question is whether energy saving technologies and building components of retrofit packages are fit for the way in which householders already are making thermal comfort in their apartments (Shove 2003) and are able to shape the thermal comfort making in the future. These thermal comfort practices consist of different elements, fusing meaning, skills and competences, and material conditions and incorporating wider societal and cultural conditions (Rau et al. 2020). Interfered by energy poverty challenges, satisfying thermal comfort has been achieved by householders at a variety of temperatures (Shove 2006). This calls for attention to a broader cross-cultural understanding of why householders use energy and how these reasons are constituting comfort 'wants' in existing use and 'needs' in emerging use of technologies and building components in their apartment (Wilhite et al. 1996; Hitching et al. 2015).

The focus of this paper is on how the material affordances of designed retrofit packages 'mediate' practical affordances in social-cultural system dynamics of thermal comfort practices. To demonstrate how diverse material infrastructures and devices in provision-based retrofitting of apartment buildings are (mis-)aligned with their socio-cultural setting (Foulds et al. 2013; Ozaki and Shaw 2014), this study chooses to draw on results from widely differing socio-cultural settings, namely those of China (Beijing and Mianyang, Sichuan province, South-west China) and the Netherlands (Amsterdam). This study takes full advantage of the range of contexts provided by this research highlighting the opportunities for comparison and contrast. In the case studies of retrofitting in these three cities, householders re-assemble new sets of material infrastructures and devices in the retrofitted apartment buildings, cope with them in various ways and continue to perform their thermal comfort practices. By doing so, our focus on the cities in China and the Netherlands, as very different research contexts, will deliver insights on multiple conditions in housing retrofitting and everyday life.

This paper seeks to answer the following question: *In what ways do material affordances of designed retrofit packages for energy saving match with practical affordances in thermal comfort practices and what are the implications for future retrofit policies in China and the Netherlands?* We take retrofitted configurations of building technology and thermal comfort practices as the functional unit of analysis. The identification of socially inclusive housing equipment for energy saving and successful thermal comfort strategies include an understanding of how and whether shifts in affective dimensions in thermal comfort practices influence energy demand in more 'closed' (prescribed) or 'open' (non-prescribed) designs of large-scale retrofit apartments. This would help circular economy policy-makers, spatial planners and the retrofit industry to develop alternative strategies for energy retrofit.

The next section presents theoretical considerations of the material affordances of the actual housing retrofit packages in relation to the practical affordances in thermal comfort practices. The section 'Methodology' presents and explains the choice of case studies and qualitative research methods. This is followed by a section presenting background information of housing equipment and thermal comfort in current retrofitting policies of China and the Netherlands. Following on the shortcomings of the current retrofit approaches, 'the householder perspective' is deepened in the 'Empirical section' , where this is extrapolated in relation to thermal comfort practices of householders. Finally, the 'Discussion' and the 'Conclusion' formulate findings, possible implications and guidelines on thermal comfort and housing retrofit from a householder perspective.

## Affordances of housing retrofit

The concept of 'affordances' offers a bridging concept to relate the crucial social role of both householders' domestic practices and the technical housing materials. This section starts with defining affordances ('Defining affordances'). Based on the chosen definition, two aspects of affordances are further described in 'Affordances as material properties of the real environment in retrofit design' and 'Affordances as perceived by an agent in a context of practical action in everyday domestic life'.

### Defining affordances

The concept of affordances is introduced by ecological psychologist James Gibson (1979) to refer to the 'in-between' of the perceiving humans and the material circumstances to investigate functional aspects of the environment. The environment shapes the actions of the perceiver, it is portrayed as an environment where almost nothing changes, fluctuates, moves or flows (Kuoppa et al. 2019). The concept of affordances as defined by Gibson emphasises the environment as the shaper of action positionalities, which makes affordances not dependent on values and meanings and past experiences.

Donald Norman (1988) deviates from Gibson in his positioning that past knowledge and design experiences may be involved in characterizing the existence of the affordance. As a cognitive scientist and one of the founding fathers of the user-centred design movement, Norman emphasises the importance of the user interface in how technical objects could be designed to encourage or constrain specific actions. With his perspective of affordances, Norman wanted to learn how the human mind works, especially in terms of human errors, wanting to teach people how to avoid making mistakes (Bucher and Helmond 2018). Norman's view on affordances remains in the realm of the designer, beyond householders' ability to perceive, select or act on them (Parchoma 2014).

To introduce a householder perspective to affordances more inclusively, Tweed (2013) and Kuoppa et al. 2019 argue that in housing studies, the concept of affordances is promising to scrutinize the designed living environment and links of experiences with technologies as integrated into domestic practices, building on Ingold (1992). The origin of Ingold's interest in the concept of affordances is based on the potential of affordances to bridge the dualism between the material world and the social-culturally constructed world (Ingold 2000). Inhabiting a house is not exclusively a question of being an operator of a physical structure, including technologies, but also a matter of preserving and creating a comfortable home organically. The home is neither just a material structure nor simply a social construct, it is a situated concept that merges social and material domains. For him, this shows that affordances need to be understood as being relational: they arise from interactions between people, the technologies and the envisioned designs of the artefacts in a practical context (Ingold 2018). In the view of Ingold, the real environment is a lived place of activities, where skills develop, and understandings of affordances are grown (Parchoma 2014; Baborska-Narozny and Stevenson 2019). By doing so, the concept of affordances becomes more closely related to the field of anthropology and phenomenology and emphasises the role of body and skills, as situated in their structured surroundings (Tweed 2013). Ingold defines affordances as:

> Affordances are properties of the real environment as directly perceived by an agent in a context of practical action (Ingold 1992).

From the definition of Ingold, two aspects of affordances could be further operationalised to study housing retrofit technologies and thermal comfort practices. In the context of housing retrofit, the first aspect of 'affordances as material properties of the real environment' becomes visible in the actual design choices for material objects which define the roles of how the householders may use the material objects to determine the usability. The second aspect of 'affordances as perceived by an agent in a context of practical action' could be located in the way the material artifacts are used by householders in their everyday lives. The latter may help to measure the usefulness of the introduced retrofitted technologies. Bringing the two aspects of affordances together in our conceptual approach, shows the connectedness of 'practical action' with the 'physical properties of retrofit packages' in such a way that it makes little sense to consider things—buildings, systems, technologies etc.—in isolation from the diverse roles of performing people involved in the design, production and eventual use (Tweed 2013).

As a result, affordances are in this paper not only considered as a designed technological construct but also as embodied in the performances of practices and thereby connected to culture, past knowledge, aspirations and experiences (Clapham 2011). So the embodied practices of householders in their context of practical action are related to the designed possibilities or obstacles of action properties in the actual material environment.

## Affordances as material properties of the real environment in retrofit design

The term housing retrofitting finds its origin in the United States in the 1940s and 1950s and describes the physical large-scale updating of outmoded housing equipment (Dixon and Eames 2013). This means 'retrofit' is about adding one or more new technologies, building systems, or equipment to the original building to specifically upgrade the functionality of the apartment. One of the main delivery models in housing retrofit is where retrofit providers coordinate the forced retrofit on the scale of the community (Jankel 2013). These programmes of regulations, incentive programmes and information provision go beyond the individualist houses to recognise the housing stock as a collection of houses within a specific geographical area (Karvonen 2018). The design of housing retrofitting equipment at the community level co-determines thermal comfort management in multiple ways. The use of the retrofit equipment is designed by retrofit providers who make implicit choices for users in housing equipment packages and settings to prompt specific responses and to constrain others (Akrich 1992). This 'standardisation' of householders' thermal comfort becomes for example explicit in the adjustment of housing equipment (Rinkinen and Jalas 2017). Thinking along the lines of material affordances, actual housing retrofitting may not only mean the development and implementation of new housing equipment for householders but also the construction of householders' roles in achieving comfort. The designs of housing equipment can be either more directive, conflicting or more social-inclusive, or flexible, complementing and hence obstructing or facilitating certain existing and newly emerging thermal comfort practices.

One option in constructing such roles through retrofit is to minimize 'misuse' by householders and dismiss them from the need to engage with optimizing building energy performance and thermal comfort, by choosing discrete options for building improvement (Karjalainen 2013; Madsen and Gram-Hanssen 2017). Householders are then considered 'passive robots', who need to use the technologies as designed by the professionals (Wilhite 2008, 2009; Moezzi and Janda 2014), or for whom 'barriers' to technology diffusion are removed by educating them in the 'correct' operation of technical devices as intended by designers (Judson and Maller 2014). The second option to a retrofit design is to give a more active role to householders in operating the retrofit products. Such a retrofit approach tends to consider householders as economically rational actors who want to optimize their thermal comfort via technologies in line with financial incentives to prevent over-consumption (Galvin and Sunnika-Blank 2017). Financial incentives are considered the easiest way to predict and guide voluntary daily consumer choices (Karvonen 2013).

Because of the great variety of affordances, Tweed (2013) and Kuoppa et al. (2019) propose to capture the whole range of affordances not only in strictly functional terms but also what is (un)desirable and meaningful or meaningless from a householder perspective. Distinguishing positive and negative sides of affordances may help to unravel different technical aspects of retrofitting, in relation to different elements of domestic practices, consisting of materials, meanings and competences. Including the whole range of negative and also positive affordances helps to do more justice to the complexity in the relationships between different aspects of affordances (Baborska-Narozny and Stevenson 2019; Kuoppa et al. 2019). Positive affordances are potentially beneficial in a householder context, with a strong fit between designed retrofit technologies and domestic practices. Negative affordances are potentially harmful in a householder context due to a misfit between both (Parchoma 2014; Coolen 2015).

In this paper, an affordance is connected to the specific resident's intentions, needs and preferences and not only an equivalent to the material 'function' (Zapata-Lancaster and Tweed 2016). This means one should go beyond simple categorizations around physical housing aspects, ownership constructions, size of the apartment, and focus instead on the experiences, and practices of dwelling. As explained by Tim Ingold (1992, 2000, 2018), these material affordances of actual housing equipment are not isolated or static constructs but part of a complicated clockwork of everyday life.

Apart from constraints, material affordances of retrofit packages afford degrees of agency, opening up a field of potential practices that would not otherwise be possible. From this perspective, since material affordances are characteristically situational and relational, the research should rather be anchored to real-life contexts.

## Affordances as perceived by an agent in a context of practical action in everyday domestic life

Social dimensions of households and (smart) retrofitting housing systems are indistinguishable from the material and technical dimensions. Housing equipment can be understood as a prefiguring composite that both shapes and is shaped by conventions, expectations and skills in thermal comfort practices. Decisive in thermal comfort practices is the interaction between people, organisations, technologies—together with buildings—and the broader socio-cultural setting. According to Ingold (2000), this offers a radically alternative way of thinking, about the meanings, as they are not attached to objects but discovered in practices. Coolen (2015) explains how a house could be described in Giddens' terms as a locale for certain social practices of the household in the course of a day; it is the place where the activities and interactions of the different members of the household take place and intersect. By using the locale's settings—for example, heating in the living room, ventilating in the kitchen and bathroom, cooling in the sleeping room and garden, and so on—such social practices constitute meaning to the activities and interactions with housing equipment.

Practices from the residents' perspective are not only functional but also desirable and meaningful (Kuoppa et al. 2019). For researching affordances of housing retrofit packages, practice theory offers new concepts for understanding how householders manage thermal comfort. Whilst this paper sets off with technological configurations in housing retrofitting, 'material' is only one of the elements shaping practices. Focusing on one element in isolation is insufficient, as also histories and trajectories of socially shared conventions, skills and past-knowledge are crucial for an understanding of domestic energy consumption. Andreas Reckwitz, defines a practice as:

> *A 'practice' is a routinised type of behaviour, which consists of several elements interconnected to one other; forms of bodily activities, forms of mental activities, 'things' and their use, a background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge (*Reckwitz 2002*, p. 249).*

Social practice theory explains how energy use via heating, ventilation or cooling equipment is linked to shared everyday thermal activities in the home (Wilhite 2008). Households do not literally 'consume' energy but utilise energy by using appliances and building components as part of executing domestic practices. The uses of the retrofitted apartment lead to new experiences, aspirations and needs (Kuoppa et al. 2019). Thermal comfort practices, as considered in this study, are characterised as regular patterns in the use of equipment for heating, cooling and ventilation and other actions taken to accomplish thermal comfort requirements (see also Hanmer et al. 2019). This could help to provide valuable insights into the timing, location, cultural context, materiality and performance of a range of interconnected thermal comfort practices related to (energy) consumption (Jensen et al. 2018).

With the focus on householders' thermal comfort practices, this paper unravels how meanings and expectations of existing and emerging thermal comfort in urban retrofitting projects are entangled in different retrofitted housing equipment which influences energy consumption (Ozaki and Shaw 2014). Central to our view on affordances are the emergent properties of practices-as-performance, like events, time-spatially situated instantiation, to analyse the properties of individual actors, groups or materials (Spaargaren et al. 2016). The objective of this research is to reveal some of the complexities related with the intervention of housing retrofitting in thermal comfort practices, which are impacted by socially shared motivations, knowledge and technologies and building components (Eon et al. 2018). This requires an emphasis on user aspects of retrofit packages in terms of thermal comfort, health, safety, affordability and traditions. Different technical user aspects of the designed retrofit packages, like its flexibility, transparency, editability and multisensory dimensions, are enabled or constrained in the practice of thermal comfort making.

## Methodology

Since affordances are characteristically situational and relational, the research should be anchored to a real everyday life context. To better understand how material affordances of retrofitted housing equipment influences practical affordances of thermal comfort, situated activities are investigated at multiple times and multiple sites. Because of the different polarised ways affordances can be experienced both negative affordances (what the retrofitted apartment cannot afford) and positive affordances (what the retrofitted apartment may afford) need to be identified (Coolen 2015). To unravel housing retrofit affordances in relation to thermal comfort practices, the qualitative method of semi-structured interviewing is used for socio-cultural microanalysis (Gram-Hanssen 2013) together with the observation of both the retrofitted apartments and the performance of thermal comfort practices. This adds the dimension of studying 'through' the subject under question rather than looking only from the outside, and brings the details of what householders actually do, as well as what they say in an interview setting. Additionally, the relevant retrofit policies on local and national scales have been covered in a literature review.

Three cities are chosen: Beijing, Mianyang in China and Amsterdam in the Netherlands. The three cities are useful candidates for comparison because they share comparable energy saving goals, while they also show some striking differences in the design and operation of their housing and energy infrastructures. Hence, the three different cities show a wide diversity in affordances of retrofit equipment for heating, cooling and ventilation, which is relevant when relating the retrofit technologies to particular thermal comfort practices in the different socio-cultural contexts. The moderate sea climate in Amsterdam and its retrofit emphasis on wall insulation and advanced technologies for heating and ventilation offers an opportunity to analyse practices of heating, cooling and ventilation. Looking for a relevant alternative in China, we decided to focus on Beijing with its cold land climate and its retrofit focus on basic district heating and roof insulation, making an analysis of heating and cooling practices possible. When doing research in Beijing, it became clear that Chinese cities in more humid climate zones, like Mianyang, have entirely different retrofit measures which are focused on building surroundings and building facades. This makes the specific practices of cooling and ventilation in this city complementary to those in Beijing. All in all, the differences between the three cities help us to include a broad range of thermal comfort practices for heating, cooling and ventilation in our analysis.

In total, 150 interviews with householders have been executed in the three cities, 50 in Beijing in June 2017, 50 in Mianyang in October 2017 and 50 in Amsterdam in December and January 2017. In China, interpreters helped with executing the interviews and the interpretations were discussed with the Chinese project team. A selection criterion for the housing retrofit projects is that the retrofit is organised at the community level and governed by the provisioning actors (local government, housing association, architectural design companies and construction companies) rather than by individual homeowners. In every city, four retrofit projects were researched to overcome a bias based on single project characteristics. Multiple case studies (Table 1) are helpful to enhance reliability and validity by more elaborative testing of the empirical findings.

In all three cities, the interviews are a mix of in-depth conversations 'inside' retrofitted apartments by using a show-and-tell strategy while other interviews were done 'outside', close to respondents' apartments in the public space of the housing estates. The duration of the interviews was between 20 and 150 min, with an average of 35 min. These interviews provided a possibility for interviewees to display their own views in their own words.

**Table 1** Researched retrofit projects in the three cities

| Name | Building year | Retrofit construction period |
|---|---|---|
| Het Breed (Amsterdam) | 1968 | 2013–2016 |
| Plesman (Amsterdam) | 1958 | 2014–2015 |
| Koningsvrouwen van Landlust (Amsterdam) | 1936 | 2009–2012 |
| Olympia (Amsterdam) | 1926 | 2010–2014 |
| Muzongchang (Mianyang) | 1997 | 2015–2016 |
| Lishan (Mianyang) | 1993 | 2015–2016 |
| Gong'an (Mianyang) | 1988 | 2015–2016 |
| Zhujianju (Mianyang) | 1997 | 2015–2016 |
| Chezhan (Beijing) | 1990 | 2015–2016 |
| Fuchenglu (Beijing) | 1986 | 2016–2017 |
| Fangzhuang (Beijing) | 1988 | 2013–2014 |
| Huixin Beili (Beijing) | 1988 | 2012–2014 |

The used topic list contained questions about general building characteristics (size of the apartment, window-direction, apartment location in the building, renting or owned, family-structure, number of bedrooms etc.), ways of heating, ventilation and cooling (What kind of technologies and low-tech strategies are you using for heating, ventilation and cooling?), affective dimensions for heating, ventilation and cooling (What are your main motivations for executing your specified ways of heating, ventilation and cooling?), the evaluation of the options for cooling, ventilation and heating after the retrofit (How do you evaluate the retrofitted building and the options for cooling, ventilation, heating, comfort and energy saving?). As the aim was an in-depth and detailed understanding, rather than quantitative descriptions, the possibilities for statistical analysis are limited (Galvin 2015). The interview transcripts have been coded and analysed for recurrent themes and key topics to develop the storyline in the presentation of findings.

## Context of retrofit equipment and thermal comfort

Before delving into thermal comfort practices in the Netherlands and China, we first explore housing retrofit in China ('Retrofit provision in China') and the Netherlands ('Retrofit provision in the Netherlands') from a providers' perspective on thermal comfort.

### Retrofit provision in China

Thermal comfort in retrofitting for energy saving in China focuses on passive technical housing improvements, by adding insulation and/or the provision of optional windows. The first state-level policy guideline for energy efficiency in the building sector was introduced in 1986 to further cover these targets in various climate zones in China (Shui and Li 2012). The first national-level retrofitting guidance on 'energy saving and emission reduction for existing buildings' was issued in 2012 when China also released its 12th Five-Year Plan. This Five-Year Plan announced a residential retrofit of 400 million square metres in the Northern district heating zone—among others Beijing—and 50 million square metres in the hot-summer and cold-winter zones without district heating—including among others Mianyang (Shui and Li 2012). The national aim is to reduce energy consumption by 16% from a 2010 baseline and by 32% from a 2005 baseline (Davoudi et al. 2014). On the local level physical aspects of residential buildings are expected to lead automatically to a 75% reduction target of the heating energy use in Beijing, and 50% in Mianyang, compared to the theoretical energy consumption of the 1980s baseline (Shui and Li 2012). Major indicators in those target policy guidelines are: centrally managed district heating, insulation and manually operated windows and window shades. Indications of householder's usage of heating and cooling in the apartments are not found in these guidelines. One of the main financial strategies to persuade householders is extensively subsidising retrofits or giving a discount on the optional window improvement and campaigns aimed at energy saving with the prospect of lower post-retrofit energy bills.

Retrofit provision in the Netherlands

Retrofit providers claim to produce thermal comfort in energy retrofitting by improving wall insulation, (double glazed) windows, mechanical ventilation and introducing new heating systems. In 1975 the first national energy saving subsidy policy was issued on roof insulation for existing housing. In 2012, the national government, housing associations and building construction companies committed to achieve a reduction of around 30% in the building stock energy consumption (110 PJ) by 2020 (Majcen et al. 2013). In 2008, the agreement 'Energy Saving Housing Associations Sector' stipulated that the housing association sector should realize 24 PJ reductions in energy consumption between 2008 and 2020 (Majcen et al. 2013). Their aim is to upgrade 1.8 million dwellings to roughly half of the theoretical energy use. In policy terms, this means an upgrade to an average energy performance label B or at least to bring the label 2 steps higher than before. The most important indicators in the energy labelling system are insulation and (semi-)automatically operated installations for heating and mechanical ventilation. No indicators are used for the actual energy consumption of householders using heating and ventilation installations in their homes. Beforehand, the householders are given a limited responsibility to influence propositions of the retrofit plan. Showing a common belief in technical fix approaches, retrofit providers typically assume that householders can be persuaded to accept the largely provider-paid standardised retrofitting activities for energy saving. The main instrument for persuading is the prospect of a (possible) lower future energy bill and higher levels of thermal comfort.

Social dimensions of thermal comfort making in retrofitting are relevant to housing retrofit in the Netherlands and in China to complement building technical solutions to cut energy consumption and $CO_2$ emissions. In general, retrofit provision has a rather top-down structure without considering existing household consumer's ways of living.

## Empirical results on thermal comfort making in the Netherlands and China

In this section, the negative and positive affordances of retrofitted equipment in relation to thermal comfort practices are presented in relation to three different thermal comfort practices: heating, cooling and ventilation.

### Heating

*Negative affordances of low-temperature heating*

The affordances of new low-temperature-heating installations tend to neglect the establishment of new thermal comfort practices due to its complexity and adjustment difficulties. In Amsterdam, low-temperature heating (LTH), made householders in retrofitted social housing complexes largely passive recipients with merely a few controls for temperature adjustment and long reaction times. Also, the radiators are generally hot on top but remain cold at the bottom. This could lead to new interdependencies and only partial energy saving. One householder explains that a turn on the heating knob of a millimetre makes a large difference, like 'playing roulette'. This is especially the case for low-temperature heating, whereby the only way to adjust it is to turn the knob (5 settings) without knowing the exact temperature. In a particular retrofit project (Het Breed), 12 of the 15 interviewed householders mention they cannot get the indoor comfort level they want and do not know how to maintain their installations. The radiant heat, quick reaction speed and cosiness of the old gas heater are appreciated although some use an additional heater or candles. An elder householder:

> *My experience with low-temperature-heating is negative because I want to adjust the temperature*

> *more when feeling ill or cold [...] The new system is less reactive, inflexible and it runs slower* (Householder #2, Het Breed, Amsterdam, 12-12-2017).

The interdependency between householders and technology appliances, such as heat pumps and solar PV, does not only refer to the ability to clean and to shut down for silence but also to usability. While some householders express lower energy costs, a couple living on the ground floor showed us their heating bill of around €700 extra yearly payment and describe their apartment still as quite cold. This reveals significant gaps between the projected re-design intent and its energy performance, and the heating bill. The householders are also not free to install another heating system which makes them feel locked into the system. Even when designed as semi-automatic systems, a blurred user interaction due to the complexity of heating systems emerges in passive counteractive thermal comfort practices, which end in a limited energy saving. This illustrates that monitoring feedback on the design is necessary to understand why novel thermal comfort practices with new installations are working as they do.

*Positive affordances of high-efficiency heating boiler*

While some heating installations of apartments in Amsterdam are getting more complex and unpredictable, the interviewed residents appreciate affordances of heating installations based on high-efficiency boilers with programmable options. Householders like to have a timer-based ‘goal thermostat’ with simple system feedback options allowing for temperature adjustments for the whole room; 40 out of 50 interviewed residents point to the removal of draft and moisture when they evaluated the options their apartment offers to control and realise ‘well-being’. Residents are only willing to sacrifice their well-being for financial considerations or energy saving to a certain extent. A householder shares:

> *I am satisfied with my new boiler with the programmable heating options. All the rooms have a radiator and it does not take much time to get the spaces up to a certain temperature [...] The radiator in her bedroom is turned off. Only when I feel very cold, I turn it on for a short time in the morning* (Householder #27, Olympia, Amsterdam, 28-11-2017).

The new heating system is interfered by humidity levels, the number of inhabitants, the location in the apartment building and how neighbours below heat their homes, resulting in occasional ‘floor heating’. When householders in Mianyang indicate that they want distributed heating, they describe a system which is cheap in use and easily changeable for different rooms. Instead of only giving financial responsibility to householders in Mianyang and Amsterdam, an improved design of new heating systems is needed to deliver predictability, feedback and quick reaction times.

*Negative affordances of automatic district heating*

The affordances of automatically operated district heating in Beijing could lead to a negative match between the retrofit intervention and householders’ needs, which can cause new problems for energy efficiency in their daily lives. The need for flexibility was observed in Beijing where adding wall insulation and offering a discount for better windows and window frames is at the core of retrofitting high-rise buildings for low-income communities. The automatically ‘upstream’ operated district heating systems still run for 24 h every day, regardless of whether the residents are at home or not. A problem is the rigidity of the improved insulation in combination with a heating system which has a rigid 24/7 working period between 15 November to 15 March and lacks control options, heating meters or real usage bills. A badly balanced district heating system can result in failures to meet energy saving targets. Only adding insulation in combination with bad engineering complicates the heat balance in an apartment building, which makes many householders dissatisfied with the indoor temperature and make it necessary to open windows to dissipate heat. Roughly 35 out of 50 interviewed residents report overheating of their apartments. While some householders have inside temperatures of 27 °C or even more, other householders still feel extremely cold. A householder mentions:

> *During the winter the district heating temperature is not high enough in my apartment. I need to heat with air-conditioning if the outside temperature is below 0 °C* (Householder #23, Fangzhuang, Beijing, 15-06-2017).

Householders in Beijing tend to critique passive affordances of district heating systems which could bring the energy saving into trouble. Narrowly defined standardised improvements give householders the experience of being 'locked-in' to new unwanted practices. In Amsterdam, the inescapability of unwanted automatic frost protection is illustrated in a heating bill of €400/ year for a poor householder who did not turn on the heating at all as a result of improved insulation. Also, in Mianyang automatic heating systems are not appreciated, 40 of the 50 interviewed householders do not desire combined wall insulation and district heating systems.

### *Positive affordances of adjustable district heating*

Some interviewed householders in Beijing experience positive affordances in suitable thermal comfort practices with regard to their 'individualised' adjustable district heating systems, after self-made re-engineering. After the retrofit of the building walls, householders in Beijing react to the current inadaptability of the central district heating with the wish 'to do what you want' to be thermally comfortable and staying warm in the winter. This highlights the 'socially negotiated' nature of emerging thermal comfort in a specific climate and calls for an evaluation of inter-occupant comfort variation and ways to manage housing infrastructures. One householder in Beijing says:

> *I am very satisfied with my personal improvement to the heating system [...] Together with an engineer, I changed the one-pipe heating system with an extra pipe circuit with my neighbor below. I can adjust the temperature a little bit better in this way* (Householder #15, Fuchenglu, Beijing, 10-06-2017).

After the improved wall insulation, 42 of the 50 interviewed householders in Beijing requested to have a simple adjustable heating system for more 'quality of life'. Their heating practices are intertwined with basic 'traditional ways of living' and 'costs'. Examples of traditional thermal comfort making are clothing strategies in Mianyang and Beijing, like long johns/autumn pants, winter pyjamas and woolly in-soles. In Amsterdam, flexible modes of thermal comfort making were observed in the use of sweaters, thick socks, flip flops and blankets. Finally, Beijing' residents are willing to pay a one-time contribution of ¥2000 (€300), roughly 25% of the householders even up to ¥5000 (€750) or more. Most residents need to use additional heating in the weeks 'before' and 'after' the district heating period because of changing outdoor climate conditions. To enable householders to save energy in relation to their thermal comfort practices, it is therefore crucial to include the seasonal weather conditions into the design of the retrofit packages.

## Cooling

### *Negative affordances of energy in-efficient air-conditioning devices*

The yearly rising use of electronic cooling devices is badly afforded in existing retrofitting designs for energy saving. Unburdening householders is not introduced in the current retrofit approach as it does not take into account residents' attempts to use technologies in the same energy in-efficient ways as before the retrofit. In retrofitted communities in Beijing, this becomes visible in the performance of practices handling thermal comfort. In one retrofit in Beijing, air-conditioning security bars are included in the building facade, but still the retrofitting does not solve the problems with old air-conditionings. The situation is problematic since incomes have risen from the late 1990s on and multiple air-conditioning devices have become prevalent. The devices are energy in-efficient and also produce noise and draught. While 5 years earlier, the majority of householders turned on the air-conditioning only in the smallest rooms after coming home from work, and only for a short period of time, nowadays, householders describe their air-conditioning usage is rising every year, notwithstanding the retrofit. In the end, the housing retrofit has not been able to counter this rise of air-conditioning usage. A couple admits:

> *Ten years ago we bought the last air-conditioning [...] We did not look into the energy label specifically, but since the retrofit we are quite interested in more energy efficient devices. We had hoped for an attractive offer by the retrofit provider* (Householder #6, Fuchenglu, Beijing, 10-06-2017).

The desire for unburdening is also the case in Mianyang, where the electricity grid is incapable of covering peak demands. To prevent over-consumption of energy, the design of electronic cooling options in housing retrofit should be linked to householder engagement in existing thermal comfort practices. In Amsterdam, the existing problem of conventional smart meters which do not measure appliance-specific energy use has not been addressed in the retrofit. Also, humidity meters are not integrated into smart meter devices and so moisture problems may remain also after the retrofit.

*Positive affordances of triangle-shaped roofs*

Positive affordances become visible in the valuation of the natural air-cooling potential of the retrofitted buildings in Beijing by adding suitable triangle-shaped roofs. This is done by matching retrofit with the priorities and interests of householders to reach the goals of energy retrofitting. Many householders in Beijing want to improve the energy efficiency of especially air-conditionings as the changing of other housing infrastructures like the shading from overhangs, window orientation, floor level and space proportioning is dependent on the regulation on security, and air- and noise pollution. However, in one project, a young couple considers positive results of the new triangle-shaped roofs and new windows to inflate cool air:

> *The temperature is acceptable after the improved roof insulation [...] During the summer we have the windows always open on both sides and the wind can blow through the apartment which is quite convenient [...] We also use turning fans during lunchtime and watching TV very often. This is more convenient than air-conditioning* (Householder #1, Cheznan, Beijing, 18-06-2017).

Emphasising cooling by natural air is important because the electricity consumption of air-conditioning is not hampered by high energy bills as these remain very low in comparison to householders' monthly expenditure. When asking for the costs of electricity, most respondents answered ‘I do not know’. Also, there were hardly any environmental concerns mentioned. To stabilise the existing trends of air-conditioning usage, 45 of 50 interviewed householders in Beijing mention ‘health’ as a driver. Health considerations drive householders to energy efficiency by regularly setting temperatures to 26 °C and rarely use the sleeping mode. One of the ideas of householders is to obtain new air-conditioners by changing the semi-automatic mode from currently 24 °C or 25 to 26 °C. In Amsterdam, health was also explicitly mentioned in 21 of the 50 interviews as important rationality towards retrofitting. Instead of using only financial incentives to realise energy saving, integration of existing health incentives in a ‘widened’ retrofit design would be helpful for the appropriation of retrofit in domestic life.

*Negative affordances of public spaces*

The way in which the retrofitted building interlocks with the design of the surrounding public infrastructures can result in negative affordances for existing cooling practices in Mianyang. In hot Mianyang's summers, householders feel the consequences of the removal of green from familiar public spaces as it could constrain the energy saving by providing limited shade:

> *I need to use more air-conditioning in the Summer which is costly [...] my apartment has become only hotter since the trees in the public space have been removed during the retrofit* (Householder #2, Lishan, Mianyang, 20-10-2017).

The large-scale centralised introduction of more parking lots makes the public space less enjoyable as a walking area and meeting place for a sense of community. A common practice of householders in China is to do a small promenade in the shared public space after the meal to contribute to digestion and to enjoy the coolness of the evening accompanied by a handheld fan. Also in Amsterdam, the urban green space, indoor and balcony plants are valued as an easily controllable and maintainable small-scale local strategy to relax and cool down. Another effect in Mianyang is that the householders become more dissatisfied with the window fences when it is 30–35 °C inside the apartments in July and August. When zooming in, most external window fences are designed to protect against garbage falling. However, the new window fences are too noisy with the water dripping down from the air-conditionings and offer, in combination with window fences, hardly possibilities to dry clothes outside. This is a problem because drying clothes inside the hot apartment can be smelly, unhealthy and takes a long time. When translating householder' experiences into the retrofit design, it is important to combine centralised, large-scale solutions and the decentralised, small-scale and low-cost solutions.

*Positive affordances of window shades*

On the other hand, an inclusive retrofit design of the building facade could include adaptable window shades with positive affordances for energy saving. Instead of costly and disruptive large-scale retrofitting of their indoor apartment, householders of Mianyang favour simple low-cost improvements of the public space, like urban green infrastructures or additional shading facilities. Depending on their preferences, householders with a southern window orientation and high floor level want to have less sunlight in the summer while the householders on the lower located floors want to have more sunlight in the winter. Also, curtains are considered less effective because the fresh air cannot enter easily and the heat is kept 'inside' the building. To leave the heat outside, the current window shades and fences do not offer enough flexible options to adjust the sunlight. Some of the householders want to be able to remove the window shed temporarily, while others want to have privacy and the 'cool look' of identical coloured enlarged window fences; 20 of the 50 interviewed householders in Mianyang emphasise the importance of adjustable window shades to have better possibilities to adjust the sunlight. One householder explains:

> *The window shades are okay [...] The flexibility and adjustability of the window shades are quite important to block the sun, especially in summer.* (Householder #25, Muzongchang, Mianyang, 03-10-2017).

The cooling potential of the flexible retrofitted window fences and public spaces appear underexploited in retrofit standards in Mianyang. Simple and familiar practical solutions of householders to counter discomfort are easily counteracted by the current generic retrofit designs.

## Ventilation

*Negative affordances of mechanical ventilation with heat recovery*

Occupants' satisfaction in the achievement of a 'cosy' living room is challenged by mostly negative affordances of too complex mechanical ventilation systems with heat recovery in Amsterdam's social housing retrofit projects. In contemporary retrofit projects, high levels of insulation have become the standard. Hence, in the eyes of some retrofit providers it is necessary to 'improve' mechanical ventilation systems and to regulate $CO_2$ levels with heat recovery. However, a challenge is that these systems are not delivering full energy savings if residents will keep on opening the windows or closing off the system, which many householders still do:

> *The idea of closing windows to let the automatic mechanical heat exchanger do the work is not understood by householders. Many windows are still opened* (Householder #48, Koningsvrouwen van Landlust, Amsterdam, 19-12-2017).

Another reported challenge of the inconvenient control features of these mechanical ventilation systems with heat recovery is that it could automatically bring in smells from the neighbours and they seem to produce a lot of dust. Maybe due to bad engineering, particular householders mention an 'explosion' of silverfishes (insects preferring humid spaces), inadequate noise insulation and some need to use a moisture absorber. Some householders describe how they cannot walk barefoot inside because of the cold floors for which they blame the obligated under-doors air gaps. Instead of the warm convection flows, householders feel automatic cold air flowing from ventilation grilles in their neck when watching television. To illustrate their active performances, residents actively use the options to cover filter vents and under-door air gaps, conceal units from view, obstruct exhaust valves or completely disable systems. These examples illustrate that to prevent bad engineering, it implies connecting retrofit design solutions to emerging performances of everyday life practices.

*Positive affordances of mechanical extract ventilation*

In contrast, other thermal comfort practices in everyday life are interwoven with more positive affordances in relation to the installations of mechanical extract ventilation in Amsterdam. After a retrofit, many householders in Amsterdam are satisfied with the replacement of the old passive stack ventilation systems. They explain that the old booster fans admittedly might be insufficient or overactive to accommodate for the humidity levels in their open kitchens, but opening windows has always been an easy solution to deal with it. This makes householders in Amsterdam more positive about the new and modern looking mechanical extract ventilation, like one lady saying:

> *What I appreciate about the mechanical extract ventilation is the automatic red warning light if the air quality is bad. This happens sometimes when I have visitors and lit candles. I like to open the windows to ventilate when this signal occurs. [...] When I start cooking, I always press the button for additional extraction for one hour. When I finish cooking, I turn it off again* (Householder #49, Plesman, Amsterdam 09-01-2018).

Householders appreciate the option to have the possibility to decide on the location of the control panel and have safety options. Also, they like to have the option to switch off the mechanical extract ventilation system in case of emergency, for instance in case of governmental notifications to close all windows and doors in cases of emergency. This shows that householders are not afraid to change the 'hardware' to achieve the indoor environment they want. The strong appreciation of having the option for natural ventilation is also a valuable insight from the interviews with householders in Beijing and Mianyang. According to residents, the retrofitting should build on existing technology-user interactions to provide a cosy home, also for relaxation, and that greatly affects indoor thermal comfort.

### *Negative affordances of bad adjustable windows*

Negative affordances of old windows occur when there is little attention to existing low-carbon thermal comfort practices in Mianyang. The householders emphasise that their old windows should be able to open completely and slightly with side-hung and/or top-hung mechanisms to provide oxygen, for safety reasons and traditional ways of living. In addition to this, householders in low-income communities of Mianyang are afraid that the current poor designs of window frames, in combination with the thin glass layer can break if they use too much heating or cooling or can fall down spontaneously. Finally, 25 out of 50 interviewed householders in Mianyang clearly state that they want to have window improvements (also to have better inside acoustic performance and improved safety) but another group of householders cannot easily imagine this. Or, as a householder mentions:

> *I do not like air-conditioning because of my health situation. I have a traditional way of living. Still, I cannot cool my sleeping room to my satisfaction. This makes me angry at the bad old windows. They are hard to slide and the design restricts to open halfway instead of completely* (Householder #50, Zhujianju, Mianyang, 05-10-2017).

For ventilation, it is no longer self-evident to combine opening windows with easily movable pedestal fans and portable table fans, which have for a long time been considered more natural and energy saving as compared to air-conditioning. All of this shows the latent need for simple traditional low-tech strategies contributing to personal thermal comfort standards and energy efficiency. Existing 'minimalised' retrofit does not succeed in the utilisation of householders' energy saving potential, especially in old communities with marginal housing. This could lead to increased energy demand after retrofitting.

### *Positive affordances of adaptable windows*

Positive affordances of retrofitted window frames in Mianyang include householders' existing experiences to deal with building elements, like the adjustability of the windows, as competitors of more energy intensive strategies like air-conditioning. This can be demonstrated in Mianyang where as a result of traditions and customs, windows are actively opened and closed every day, in combination with the use of bamboo mats during the night to stay cool. Sweating is here considered as a natural, healthy part of life especially by elder householders. In Wintertime, many householders wear a winter coat inside their apartment or use footbaths, (electric) blankets and (electric) hot water bags. The limited opening options of the damaged windows—since a major earthquake hit this region in 2008—in combination with the strongly growing availability of air-conditioning devices and other electrical devices, have slowly changed the more 'traditional' thermal comfort practices. In relation to their new windows, residents appreciate the opening options and options to provide natural light:

> *In addition to using his electric blanket and inside coat wearing, I like the new top-hung window type because it offers more fresh air. I also think the double glass layer is better. Besides, I like the blue*

*color* (Householder #36, Gong'an, Mianyang, 04-10-2017).

If householders use adjustable windows and window fences, instead of using mechanical technologies, they use 'elastic' definitions and flexible interpretations of thermal comfort. For retrofit design, a better inclusion of manual retrofit packages could capture existing affinity in flexible thermal comfort definitions, instead of solely focusing on a 'fixed' ideal thermal comfort.

## Discussion

Our conceptual framework around 'affordances' (Ingold 1992; Kuoppa et al. 2019) offered a way to discuss thermal comfort practices and dwelling characteristics in a relational way, with positive and negative sides taking into account the contextual circumstances and atmosphere. The theoretical approach of our study is built on the notion of 'material affordances' as designed usabilities, next to 'practical affordances' in which actual usefulness contributes to a meaningful way of conceptualising roles of householders in appropriating the retrofitted apartment. In our approach, the knowledgeable household-consumers were conceived of as active co-designers of 'thermal comfort practices' which are fundamentally social, political and contextual. By using practice theory, we showed that the interrelations between 'practical affordances' and 'material affordances' are structured and routinized in particular ways by several elements (material objects, ideas, competences and meanings) that can be specified through empirical research. This implies that a more integrated perspective of how consumers and technologies interact can be used. From this viewpoint, we were able to discover that existing practices die and new practices emerge in co-evolution with the new building equipment, which in turn construct new needs and wishes in people's everyday life. For future energy policy making, it is significant not to concentrate exclusively on residents' behaviour, technology or building components, but to question how to advance low-energy practices rather than buildings.

While analysing retrofit packages for heating, cooling and ventilation in the three cities (Table 2), we observed that the specific problems and solutions are not evenly distributed over the case studies of the three cities under study. The low-tech retrofit of windows and outdoor spaces in Mianyang makes usability and familiarity a special key for their retrofit policy, while the uniform retrofit of insulating triangle-shaped roofs and district heating systems in Beijing seems to make unburdening and flexibility particularly stringent. The more technical retrofit approach via complex installations of heating and mechanical ventilation in Amsterdam seems to urge the importance of system feedback and simplicity. Complex or strict adjustment in housing equipment does not just expel the likelihood that householders can be inactive in some respects and active in others. Retrofit providers likewise easily overlook the way that end-users employ different forms of knowledge, competence and rationality in approaching their regular day-to-day life. In their thermal comfort practices, Amsterdam householders are for instance more motivated by thermal well-being and relaxation while householders in Mianyang emphasise natural, traditional simple ways of living. Householders in Beijing are more engaged with health and companionship. The ability to influence housing equipment in their living environment consents householders to develop skills to better control their own socially and culturally suitable levels of thermal comfort. This would not make social practices or energy demand more predictable, but rather results in more flexible housing equipment, irrespective whether they provide more or less adjustment options. Every retrofit context has its own challenges and opportunities to include householders.

From a householder perspective, one needs housing equipment that is adaptive to householders' use and control to achieve energy saving targets. This call for adaptive housing equipment is equivalent for the three case cities, no matter the different retrofit packages that are found in provided housing equipment. Especially householders in Beijing highlight their preference for energy efficient air-conditioning units in their apartments after the retrofit. They oppose the lack of adjustment possibilities of their heating systems. Similar to the challenges residents have with heating in Beijing, also Amsterdam residents urge for more possibilities to influence their automatically operated mechanical ventilation technologies and semi-automatically operated heating technologies. With the retrofit providers' focus on 'fixed' thermal comfort, aspects such as ease of control, ease to customize, ease to organize feedback, ease to maintain and to silence, seem to be disregarded. The findings from householders in Mianyang illustrate that manually operated housing equipment, such as

**Table 2:** Different cities and positive and negative affordances, meanings and policy contexts.

| | Negative affordances | Positive affordances | Meanings | Policy context of housing features |
|---|---|---|---|---|
| Amsterdam | Poorly adjustable low-temperature heating | Programmable hot water boiler heater with timer | Well-being | Predictability and system feedback |
| | Complex mechanical ventilation with heat recovery | Flexible mechanical extract ventilation | Relaxation | Controllability and simplicity |
| Beijing | Old air-conditioning devices | Unburdening triangle-shaped roofs | Health | Suitability and unburdening |
| | Automatic district heating | Adjustable district heating | Companionship | Level of automatisation and flexibility |
| Mianyang | Difficult to open windows | Easy adaptable windows | Natural ways of living | Adaptability and usability |
| | Limited shade in public space | Adjustable window shades | Traditional ways of living | Refitting and familiarity |

windows and window shades, need to be designed in a way that enables them to make them fit with their everyday lives. In general, they are more willing to use manually adjustable building elements rather than complex socio-technological systems, which are often costly, complex and inefficient to use. This stresses the importance of social-inclusive and adaptive designs of housing equipment in housing retrofitting. All types of new housing equipment interfere with householders' everyday life, which leads to uncertainty about the demanded scales of user-freedom and how this links with, for example air-quality, safety, privacy and sound demands. Connecting the challenges in housing retrofit more directly to the everyday lives of householders could mean becoming more sensitive to the different ways of decision making about the scope, quality, and costs aspects of the retrofit items.

On a practice level, instead of only providing technical fixes, housing retrofit providers should identify and distinguish the specific thermal comfort practices performed in pre-retrofit stages, such as those explored in this paper. Challenges in existing thermal comfort practices regarding technology and housing equipment could be better integrated into the housing retrofit. Taking householder inputs that reflect householders' wider experiences could re-frame retrofit design in housing technologies. Householders in the three cities value their simple low-tech solutions such as adaptable windows, fences and shade options. This makes householders not always optimizing their ideal thermal comfort level but accepting a minimum level of existing comfort. Adaptive strategies, like wearing more clothes in the winter, could be regarded as relevant energy saving strategies without sacrificing comfort. Acknowledging these personal adjustment options could potentially prevent householders from obstructing currently too narrow technological scripts. These specific needs of adaptability emerge also in the new thermal comfort practices, together with the new retrofit packages. As a result, innovation in domestic practices can be initiated by different practice elements (objects, skills, meanings, emotions and goals) from the provisioning side as well as the consumption side. The message of this paper is to cater for such end-users' perspectives in housing retrofitting and thereby integrate the complexity of comfort and home ambiance.

Affordances essentially offer a contextual approach to thermal comfort in housing retrofit including a comprehension of two scales (the material and the practical). In the fit between householders and thermal comfort are material and social requirements in a continuous rearrangement. The perspective of affordances helps to understand the active role of the householders in finding, shaping, and creating practical affordances in a process of thermal comfort making in their apartments. A focus on practical affordances of thermal comfort may lead to new quality requirements, including notions of wellbeing, sense of community, freedom and security. All in all, these socio-material constellations push the retrofit constructors to provide qualities beyond elementary technical functions that are attached to the perceived affordances of retrofit design. Translating these thermal comfort purposes to retrofit products, they may need to provide modern, warm, light, quiet and convenient retrofit packages. Utilising the lens of affordances for future retrofit policy on thermal comfort would take the socio-cultural contexts of technologies into account. This would draw retrofit designers, urban planners and energy consumers into further communication and learning from each other in the design process. To concretise, recommendations are to use extensive explorative pre-design sessions and thorough communicative interactions with residents with the purpose to validate the design. By doing so, retrofit providers would take into account the wider social settings and mechanisms that support specific thermal comfort practices.

Lastly, from a policy perspective, the 'smartness' of urban retrofitting should refer to the inclusion of end-user perspectives in China and the Netherlands. By doing so, this research has taken a dynamic, process-oriented and contextual perspective on retrofit projects as the main points of reference in organizing the research rather than a countrywide comparison. General studies on the national level are helpful for a general overview but they tend to ignore within-country differences and, more importantly, the complexity and the more profound nature of the studied issues (Gómez and Kuronen 2011). This study is modest in the possibility to capture the complexity of both countries and takes both countries as 'the context of study' instead of as 'the unit of analysis'. The policy implications of energy retrofit supply and use do not depend on the actions of householders or retrofit providers separately, but on both together. Differentiation in production and consumption inherently points to enhanced consumer involvement. This means focussing on the local retrofit context, understanding and reconciling the different perspectives and involvements of the different stakeholders, but keeping the energy saving criteria in the loop. Extrapolating on the links between and among thermal comfort practices and other domestic practices (for example cooking, showering and washing and laundering) has potential for further study to develop knowledge around the stability, biography and trajectory of practices. Eventually, also a distinction between different spaces in the apartment (living rooms, sleeping rooms and outdoor spaces) could be beneficial. Instead of starting from specific predefined retrofit packages, retrofit providers would do better to start from the sustainability goals, and then together with the householders generate ideas, technologies and actions for a retrofit that suits prevailing thermal comfort practices.

## Conclusion

This paper set off with the question: *In what ways do material affordances of designed retrofit packages for energy saving match with practical affordances in thermal comfort practices and what are the implications for future retrofit policies in China and the Netherlands?* The study of heating, cooling and ventilation in three cities Amsterdam, Beijing and Mianyang demonstrates that thermal comfort cannot be solely delivered by technologies or passive building elements of an apartment but should rather be conceived as an accomplishment of existing and emerging thermal comfort practices. These findings contrast with the modes of conduct of both Chinese and Dutch retrofit providers, who strongly rely on the provision of new technologies, passive building elements and financial incentives to realise the energy saving. Using performed affordances of existing and emerging thermal comfort practices as an analytical lens to focus on retrofit packages has helped us to show how energy demand is being co-determined by the creation of comfortable homes. Occupants of retrofitted apartments are not just 'users of buildings' but 'householders' who realise comfort through their domestic practices. It proved relevant to look at the different cultural contexts of China and the Netherlands to analyse a broad range of strategies for residential thermal comfort making in relation to different retrofit packages. The relevance of analysing different retrofit packages helped to understand that creating a 'fit' with thermal comfort is not limited to one type of retrofit. Instead, including thermal comfort is a combined effort to be made across retrofit packages adapted to specific local conditions.

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**Compliance with ethical standards**

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